Department of
Environmental Quality

An Evaluation of the Potential for Ground Water Contamination by Transport of Petroleum Products over the Rathdrum Prairie Aquifer

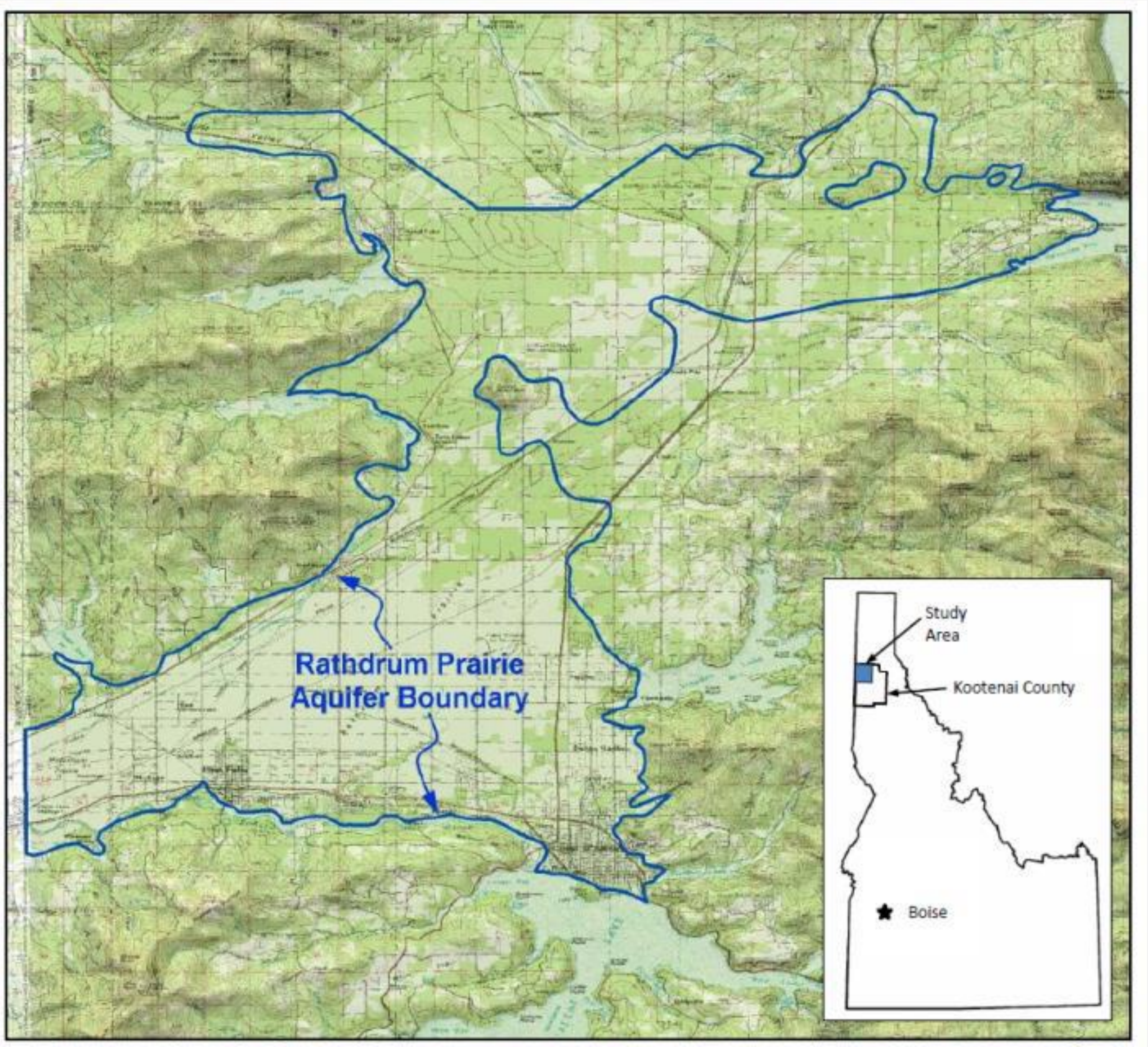
Gary Stevens P.G.

IWAC Meeting
Liberty lake, WA
September 13, 2016

RPA Petroleum Transport

- Study Area
- Petroleum Types and Transport
- Volumes Transported Over the RPA
- Dakota/US Transport of Crude Oil
- Historical Releases
- Petroleum Properties
- Fate & Transport Models
- Model Results

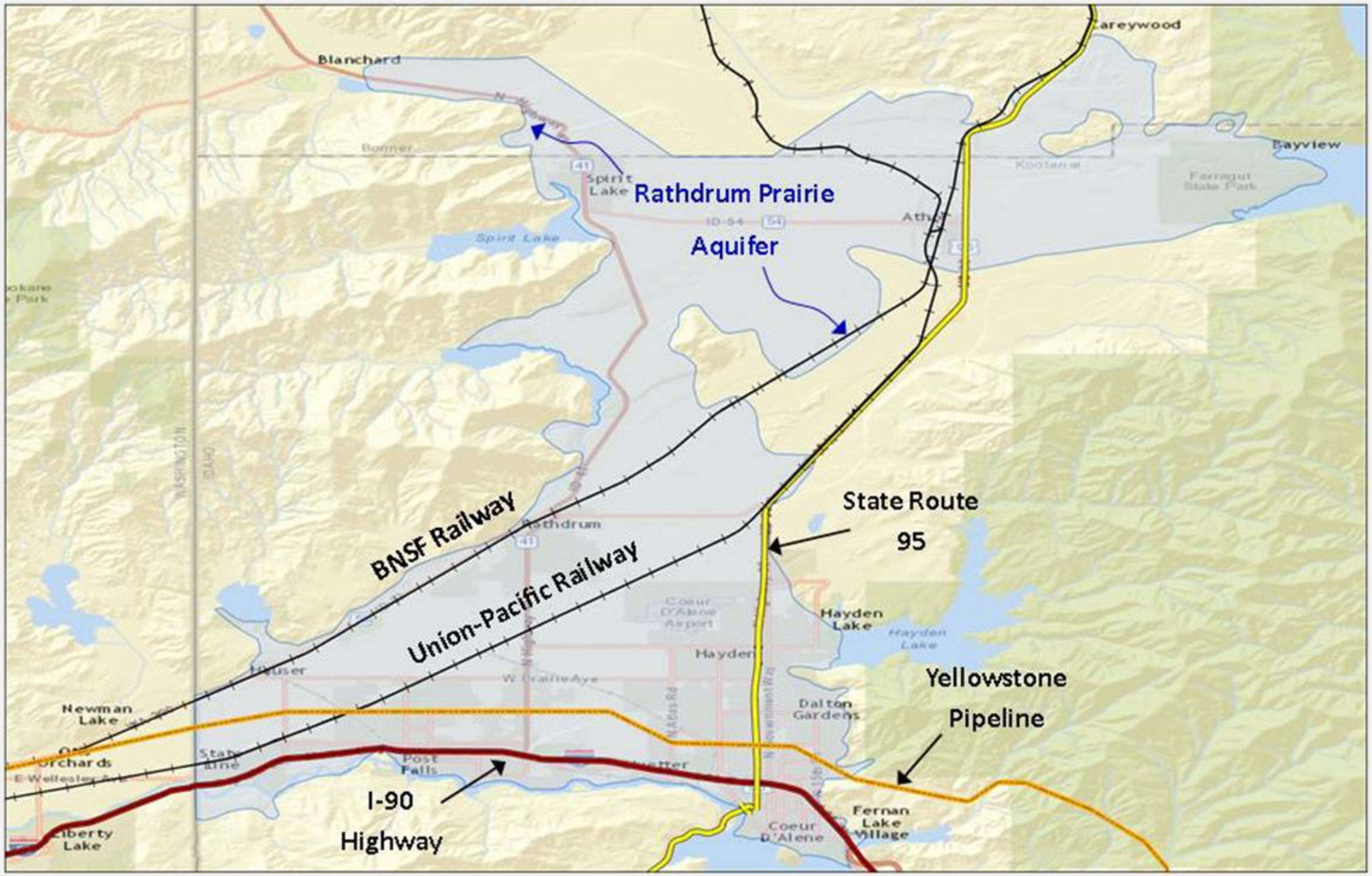
Study Area



Rathdrum Prairie
Aquifer Boundary
Study
Area
Kootenai County
Boise

Petroleum Types and Transport

- Truck Transport of Gasoline and Diesel
- Rail Transport of Bakken Crude Oil and Ethanol
- Pipeline Transport of Various Refined Petroleum Products



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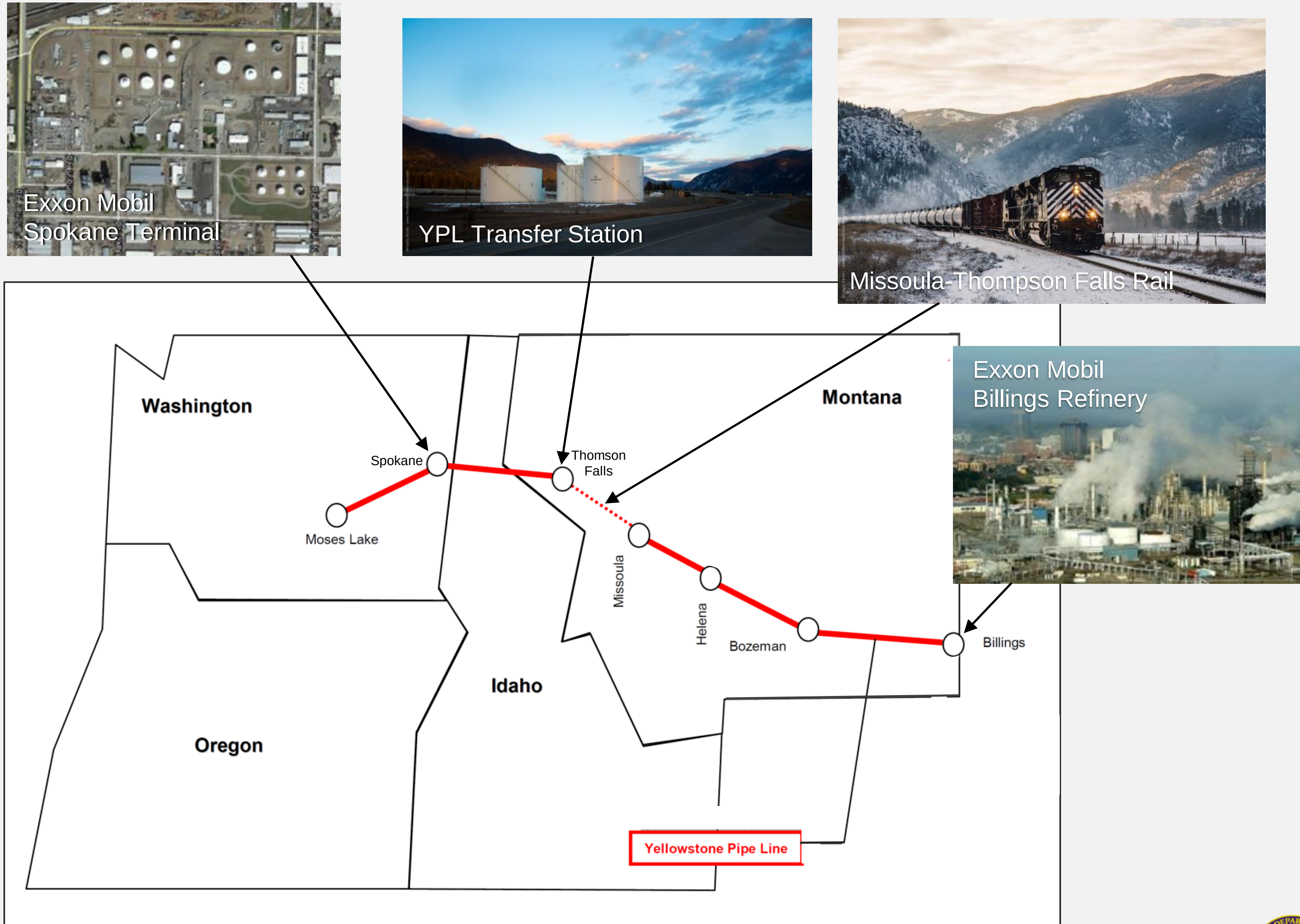
Petroleum Types and Transport – Truck Transport

- Transport refined petroleum from distributor to retail outlet
- Tanker trucks carry approximately 1,000 to 9,000 gallons
- Main routes for distribution I-90 and SR-95
- Volume Estimate
  1. Weigh Stations – ITD information not sufficient to determine volume
  2. Retail Petroleum Taxes ($0.32/gal) – Idaho State Tax Commission fuel is taxed at distributer not retail outlet. Could not isolate to Kootenai County
  3. Number of Registered Vehicles – ITD database with number of registered vehicles for each county

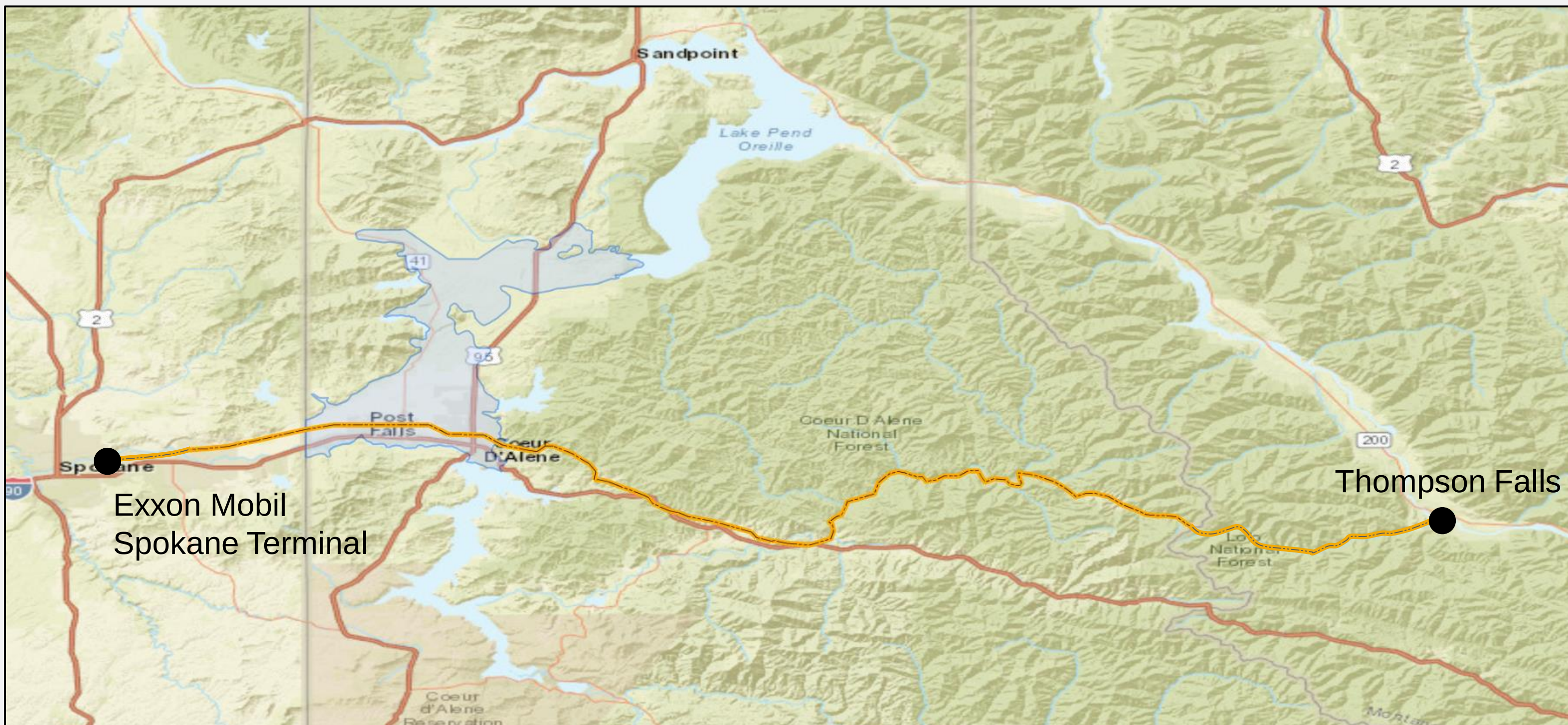
Gallons per year = Number of registered vehicles * EPA est. of miles driven per year / EPA est. of mpg
= 77,981,194 gallons per year
= 213,647 gallons per day

Petroleum Types and Transport – Yellowstone Pipeline

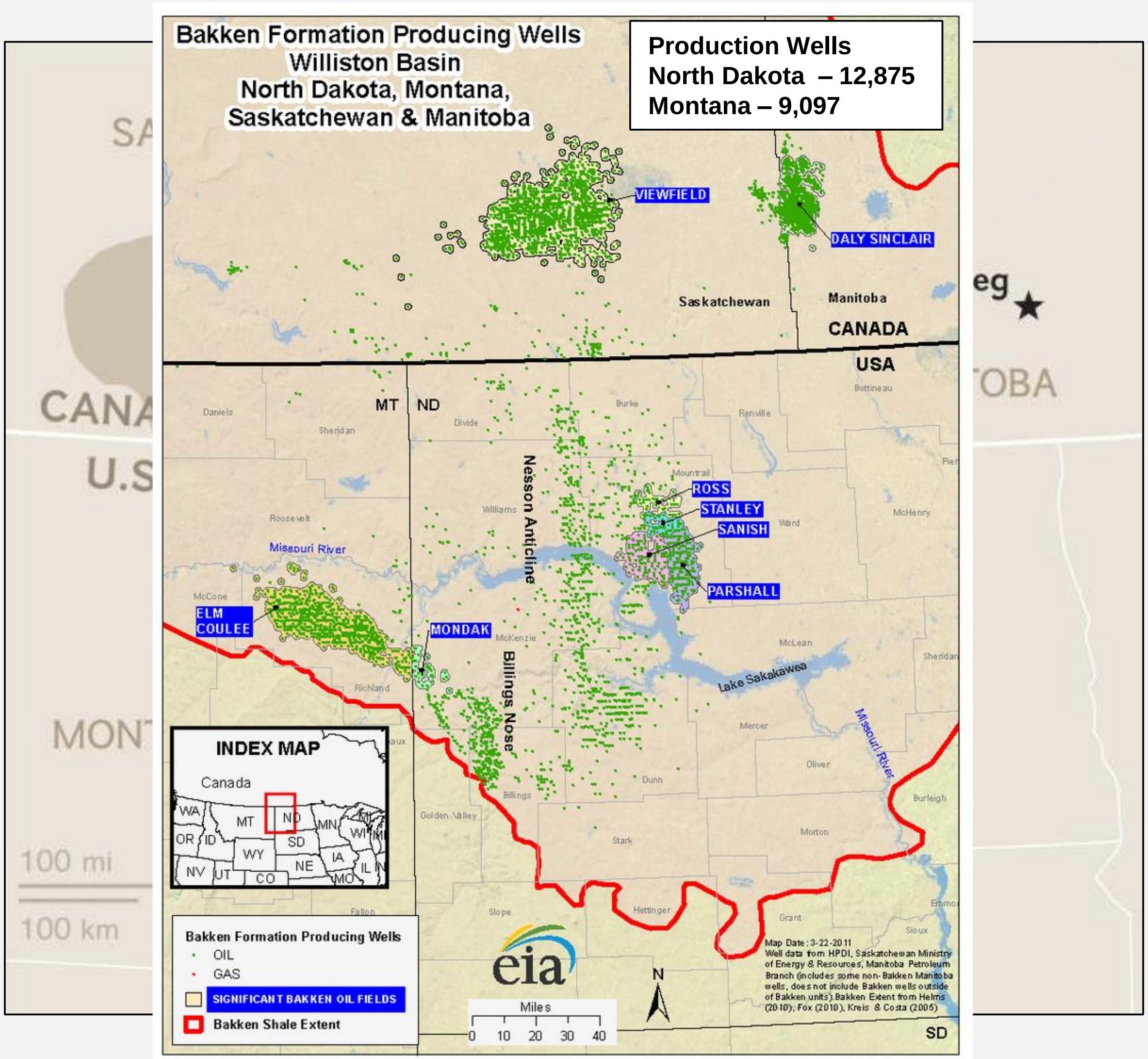


Petroleum Types and Transport – Yellowstone Pipeline

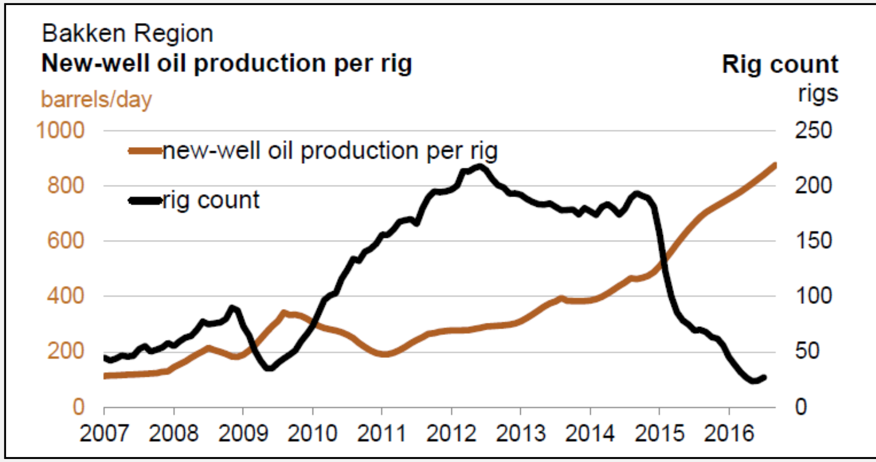
- Constructed in 1954
- Buried 10 – Inch Diameter Steel Pipe
- Operates at ≈ 900 psi
- Crosses over the 14 miles of the RPA
- Transports gasoline, diesel & jet fuel
- Capacity = 66 thousand barrels per day (2,772,000 gallons per day)

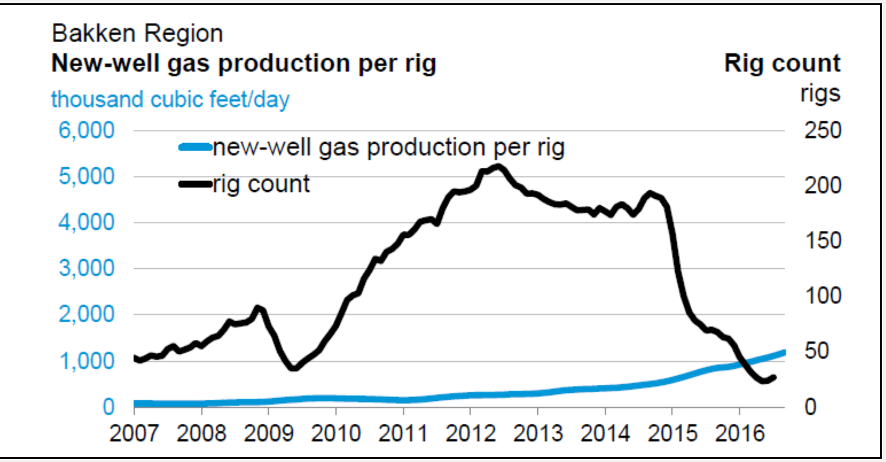


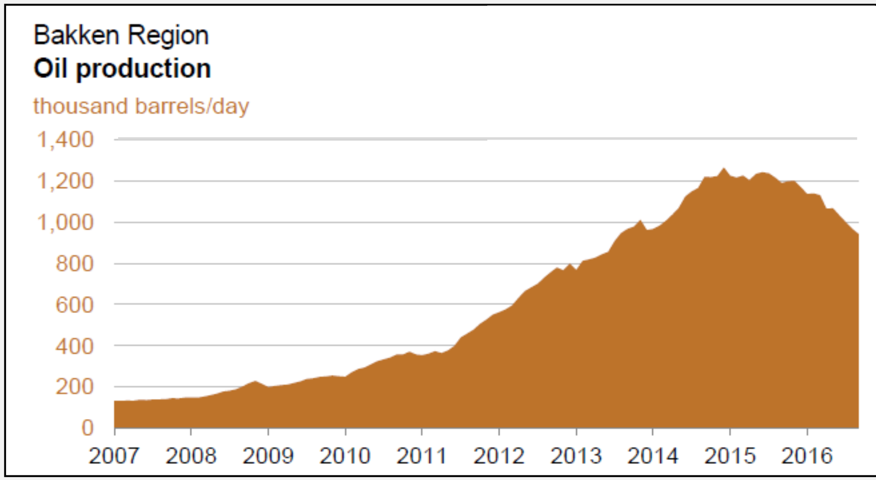
Petroleum Types and Transport – Rail Transport Bakken Crude

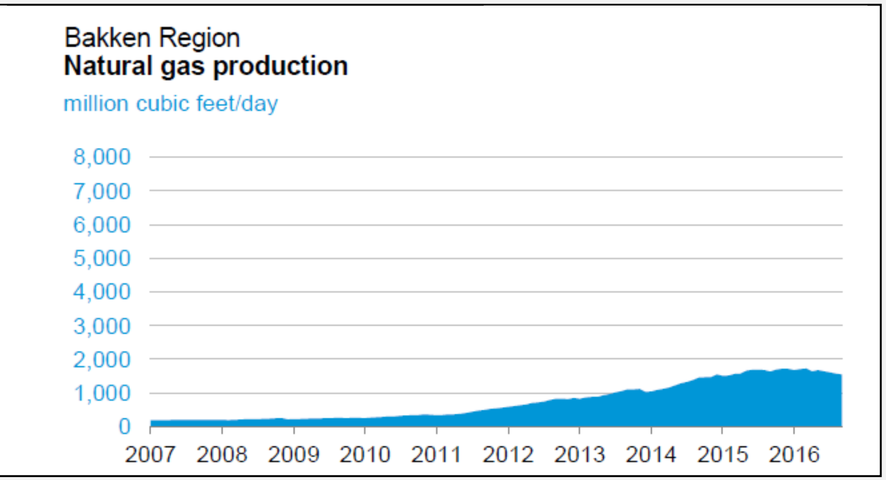


Petroleum Types and Transport – Rail Transport Bakken Crude

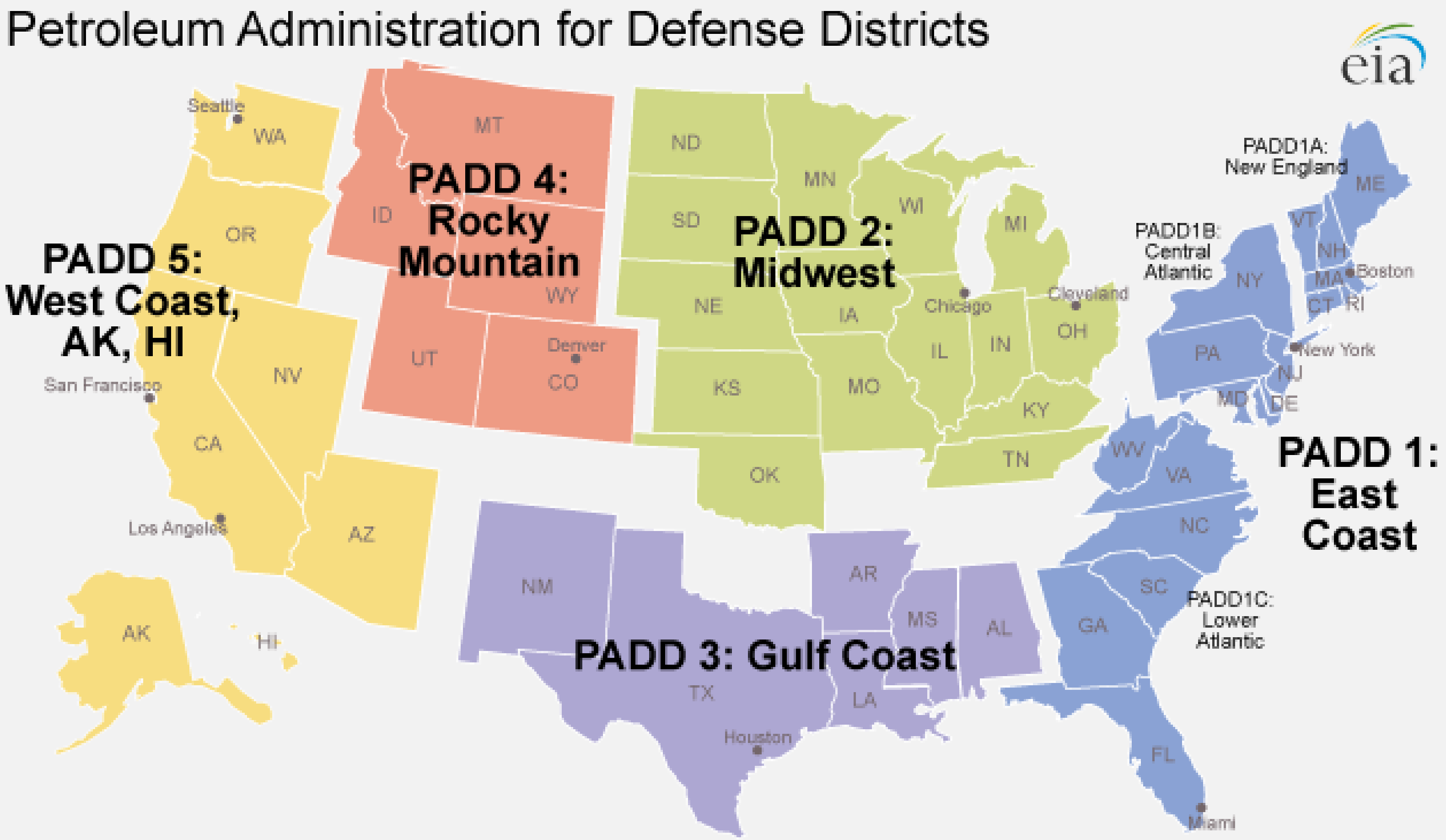








Petroleum Types and Transport – Rail Transport Bakken Crude



These were created during World War II to help organize the allocation of fuels derived from petroleum products, including gasoline and diesel. Today, these regions are still used for data collection and analysis.

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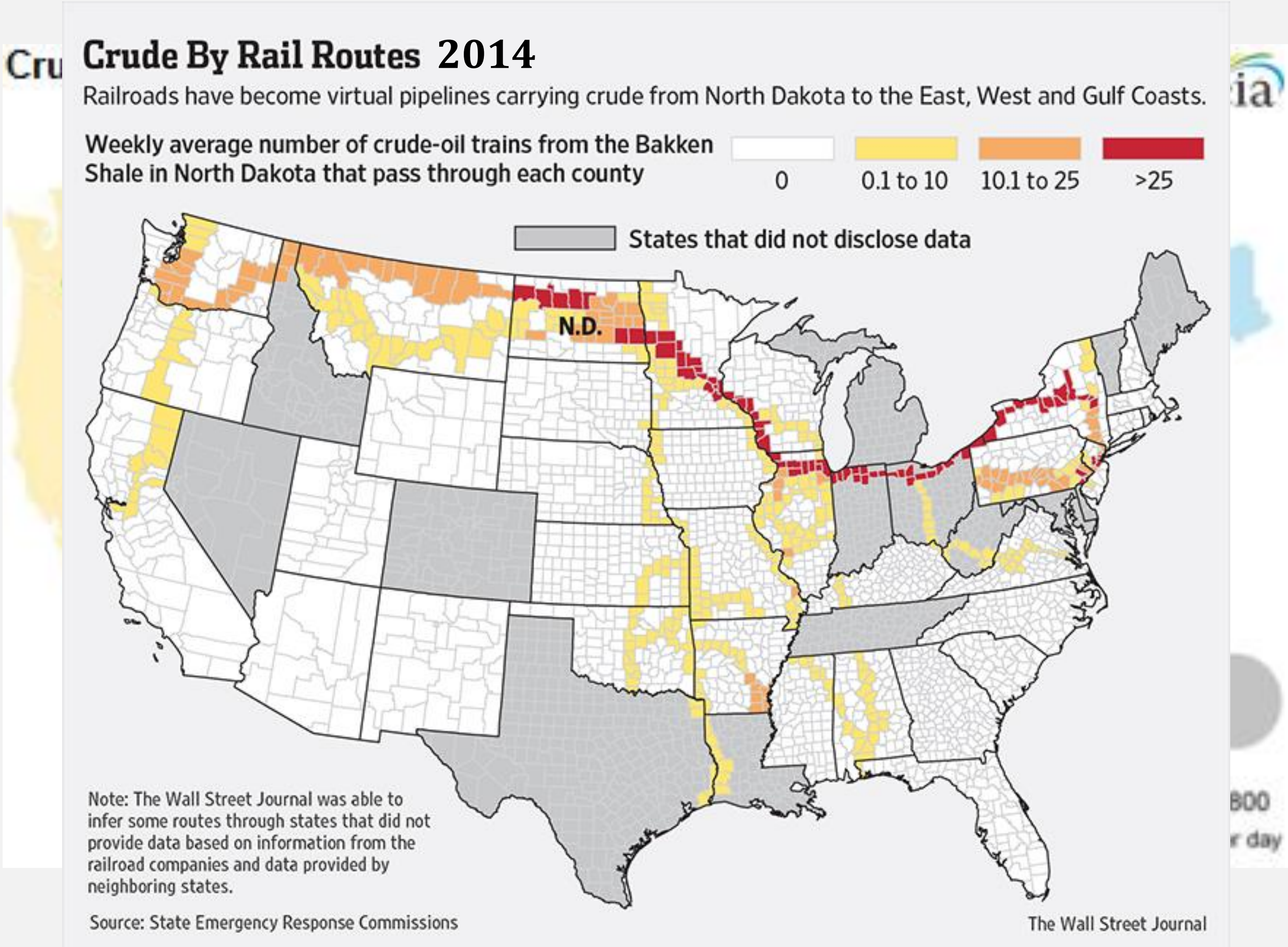
Petroleum Types and Transport – Rail Transport Bakken Crude



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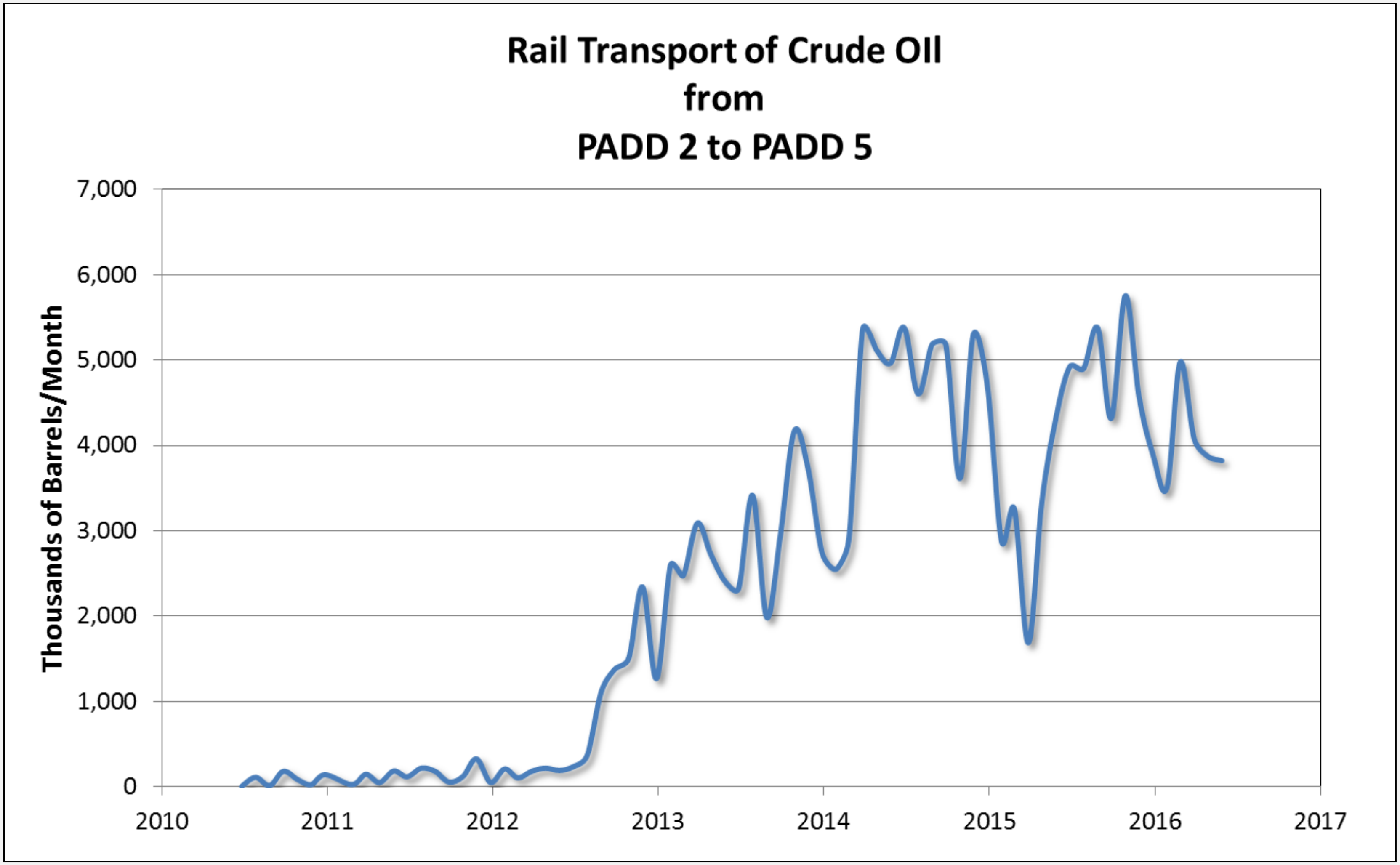
Petroleum Types and Transport – Rail Transport Bakken Crude



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Petroleum Types and Transport – Rail Transport Ethanol

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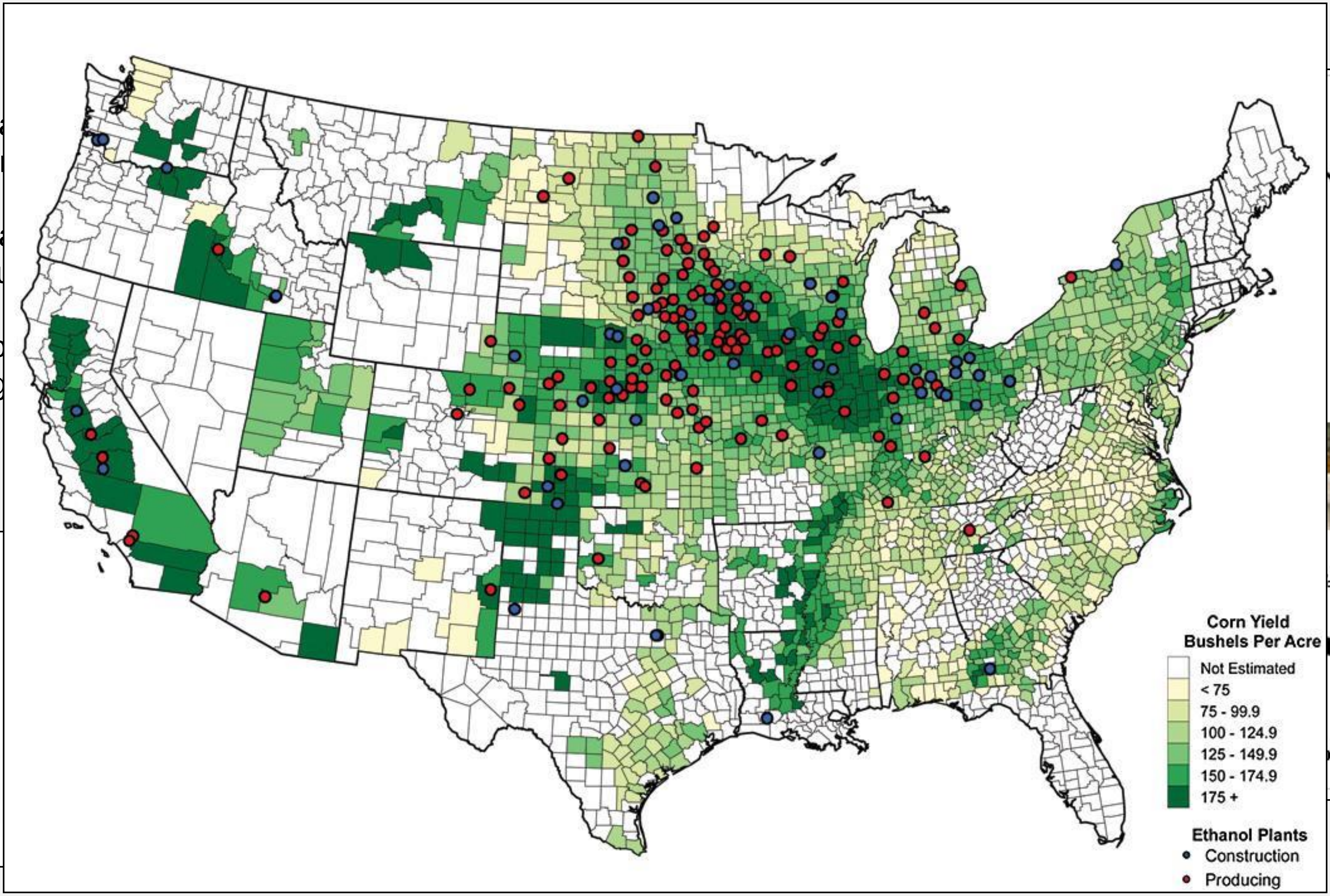
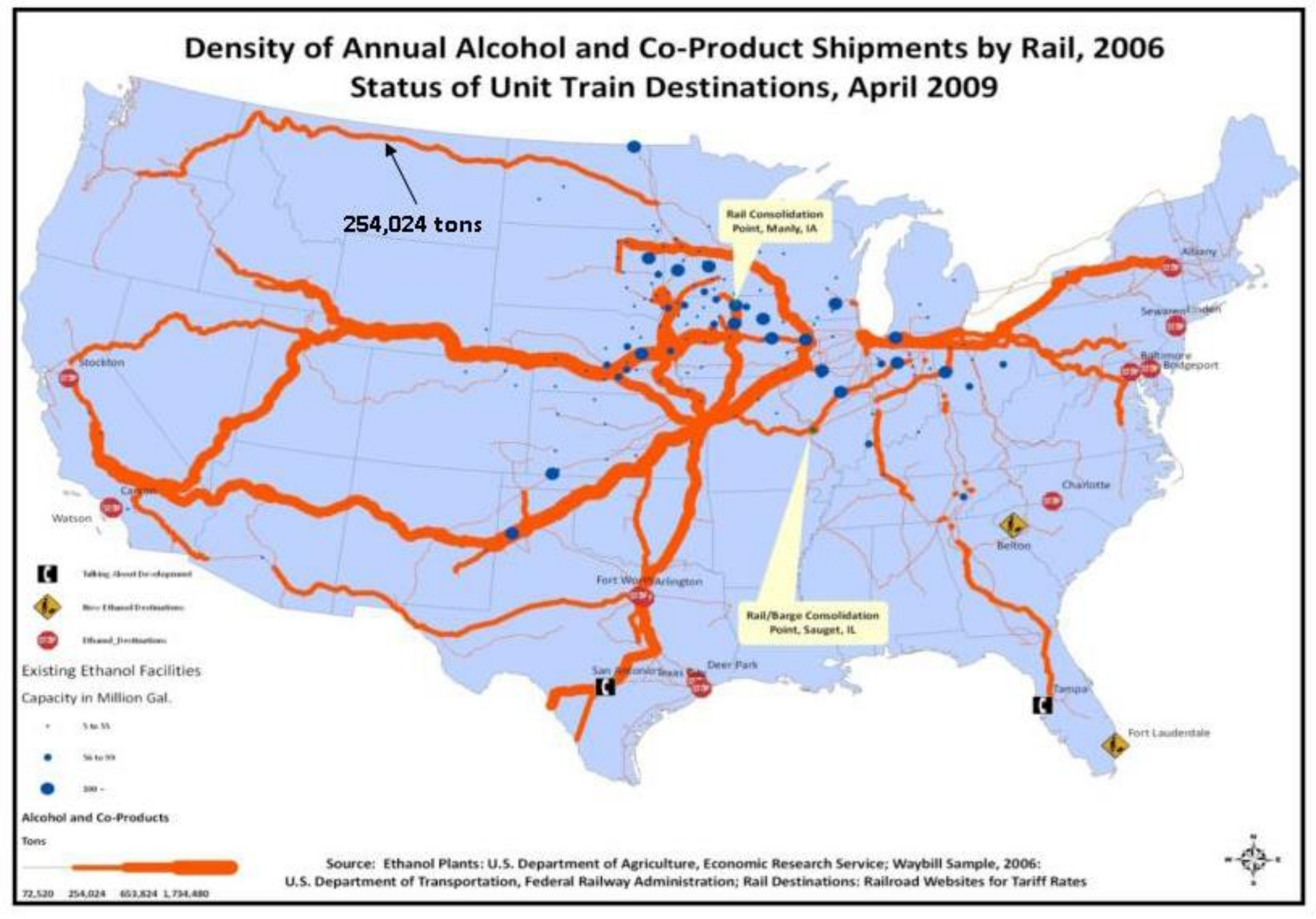


Petroleum Types and Transport – Rail Transport Ethanol

Ethanol Transport Volume over the RPA = 179,623 gallons per day



Study of Rural Transportation Issues, USDA, Ag. Marketing Service (2010)

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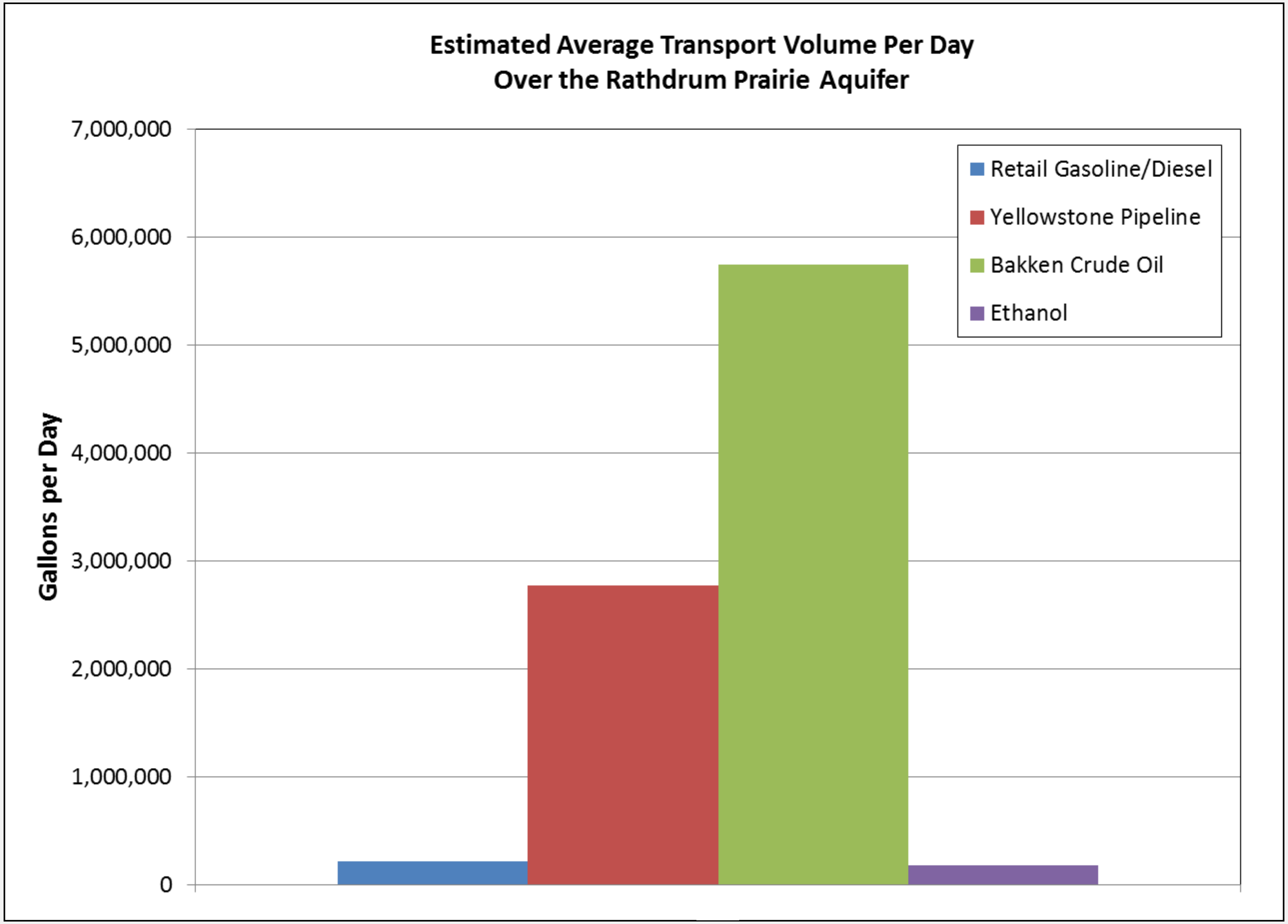
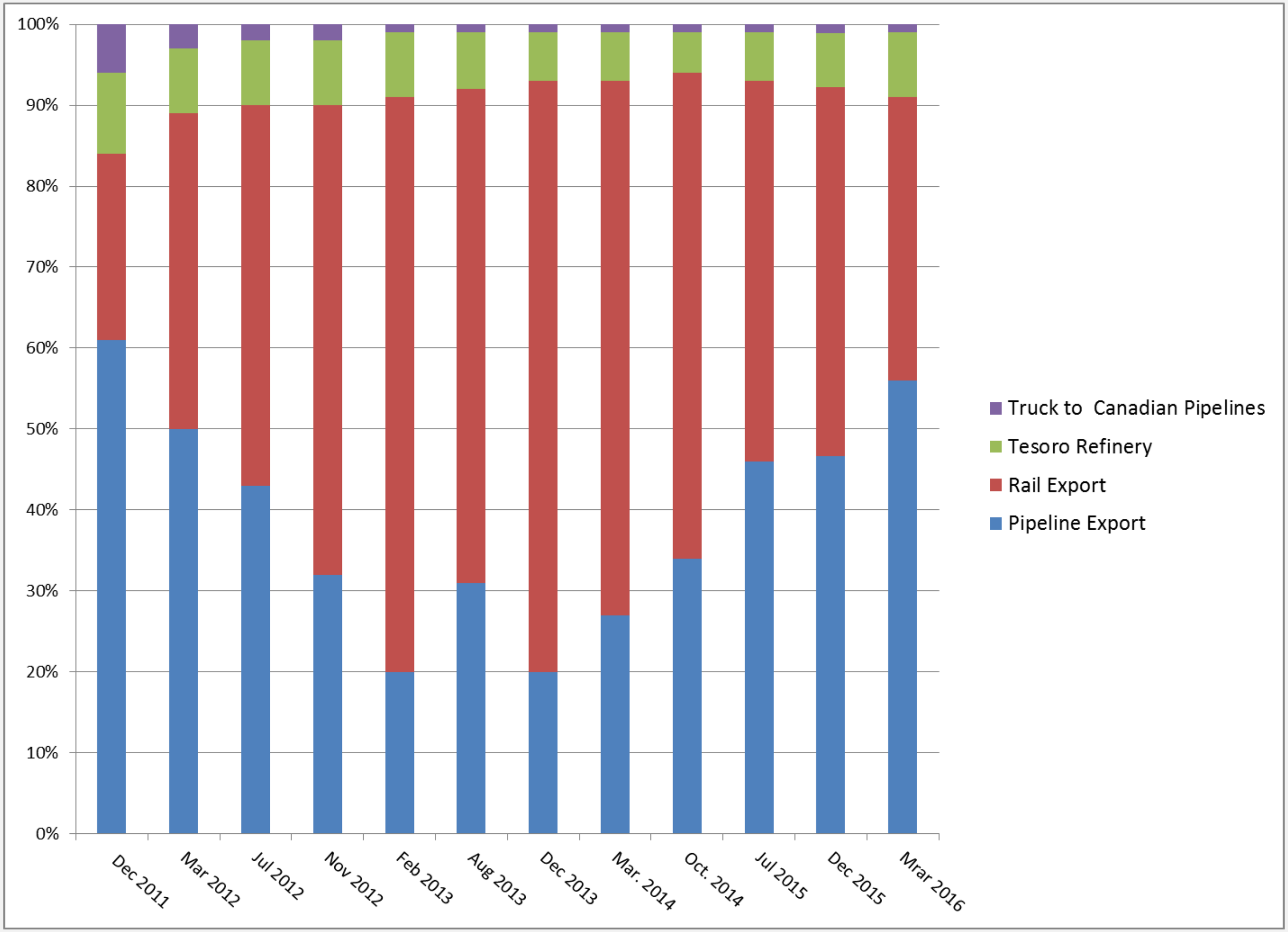
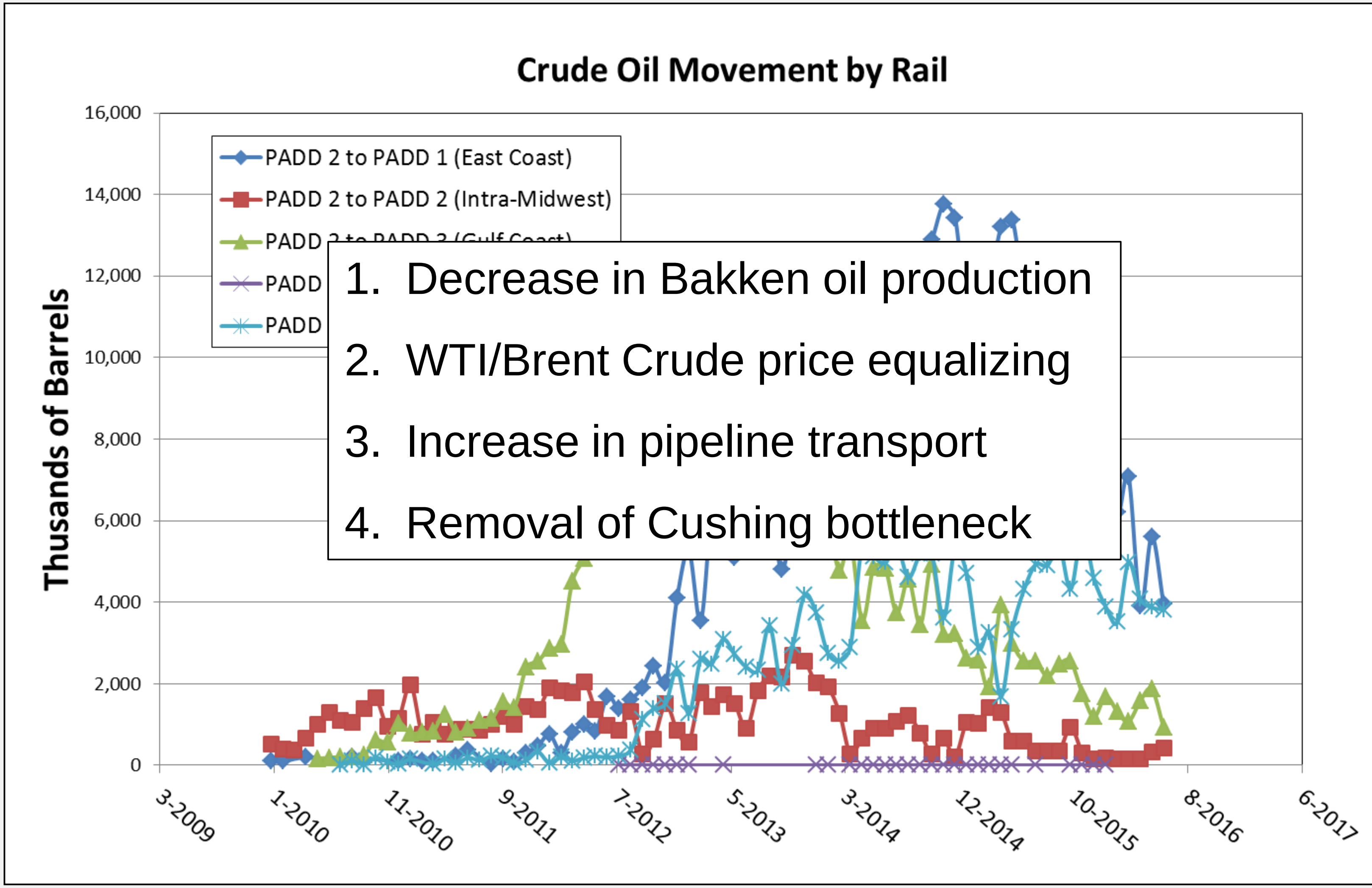
Volumes Transported Over the RPA



Dakota/US Transport – North Dakota Crude Oil Transport



Dakota/US Transport – East Coast



1. Decrease in Bakken oil production
2. WTI/Brent Crude price equalizing
3. Increase in pipeline transport
4. Removal of Cushing bottleneck

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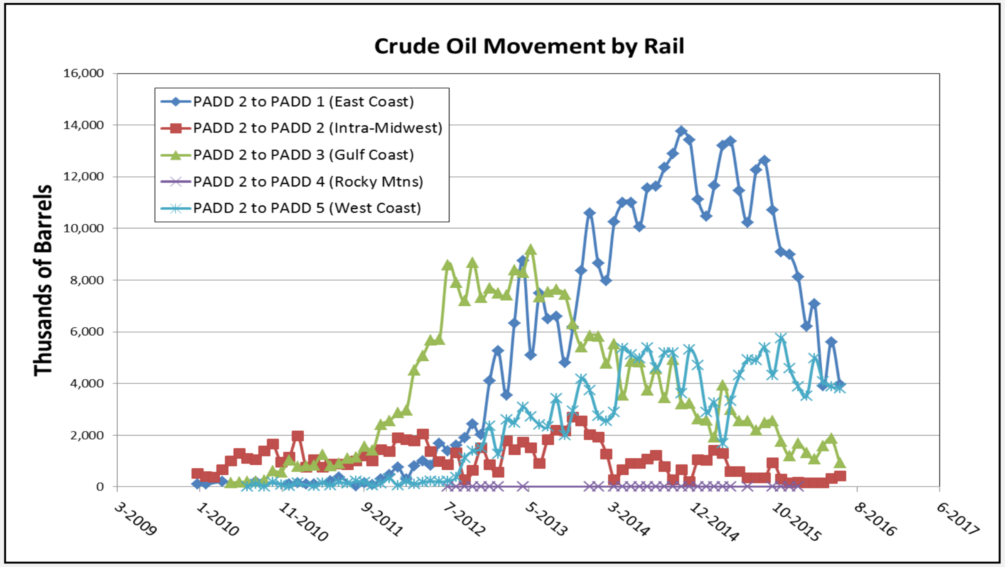
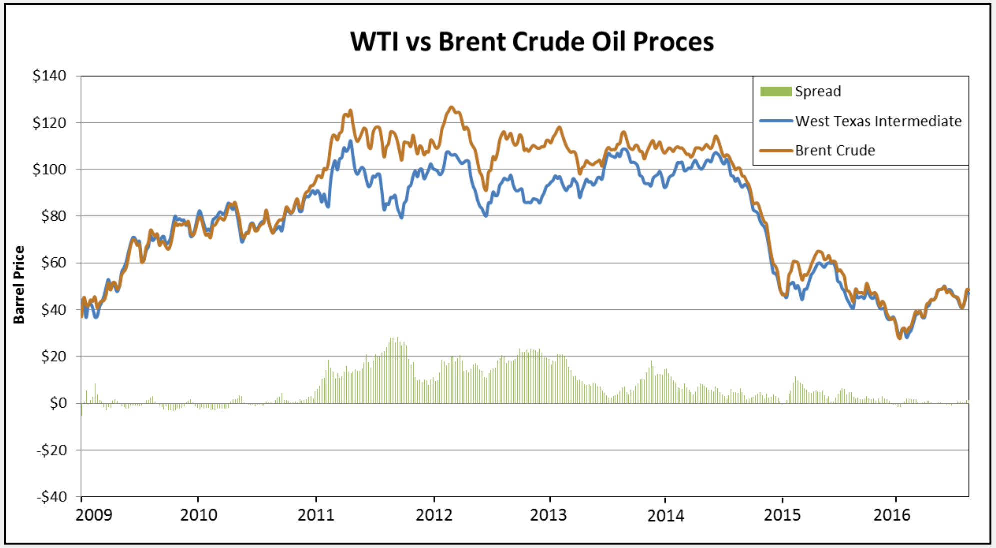
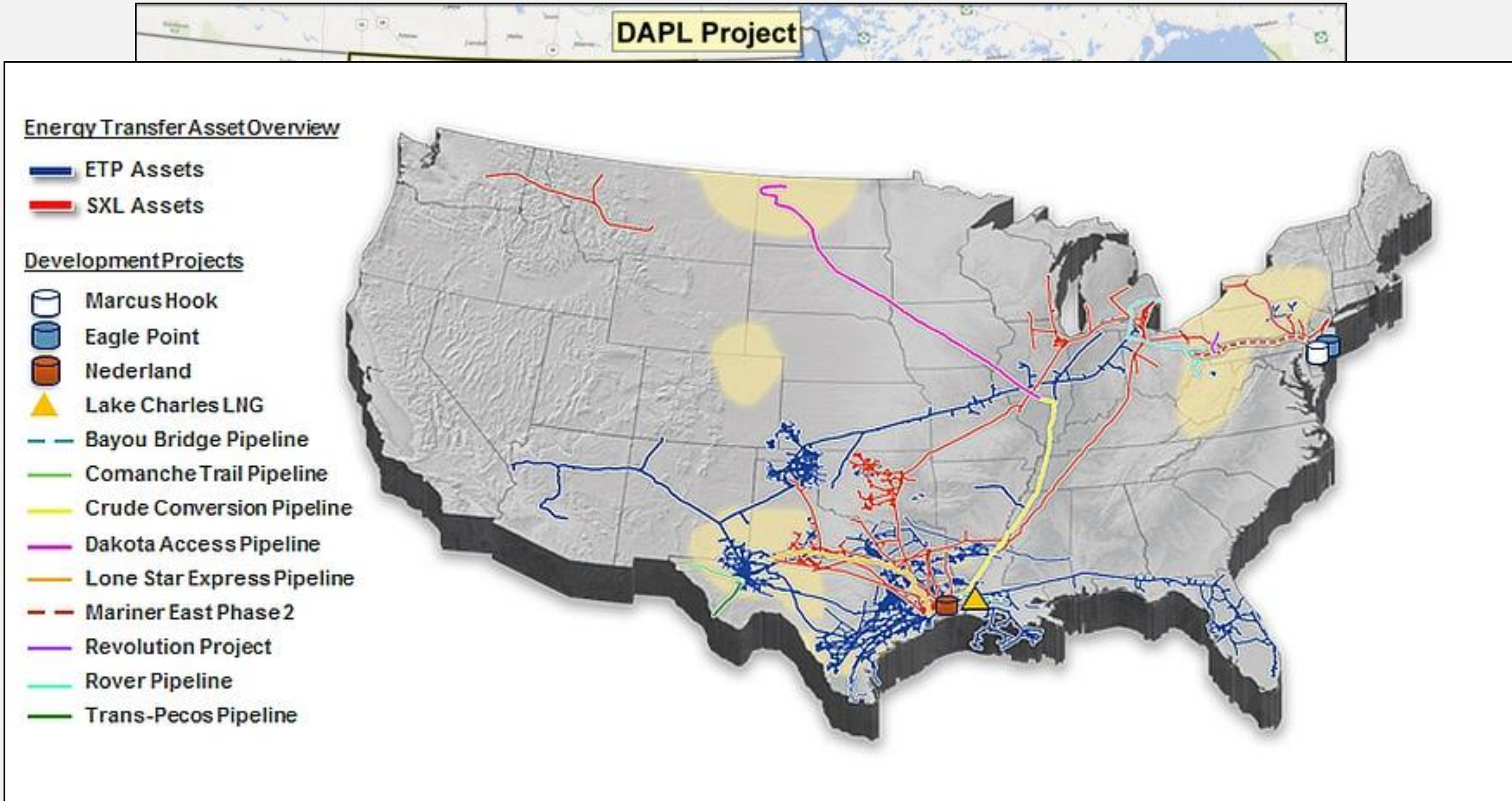
Dakota/US Transport – East Coast



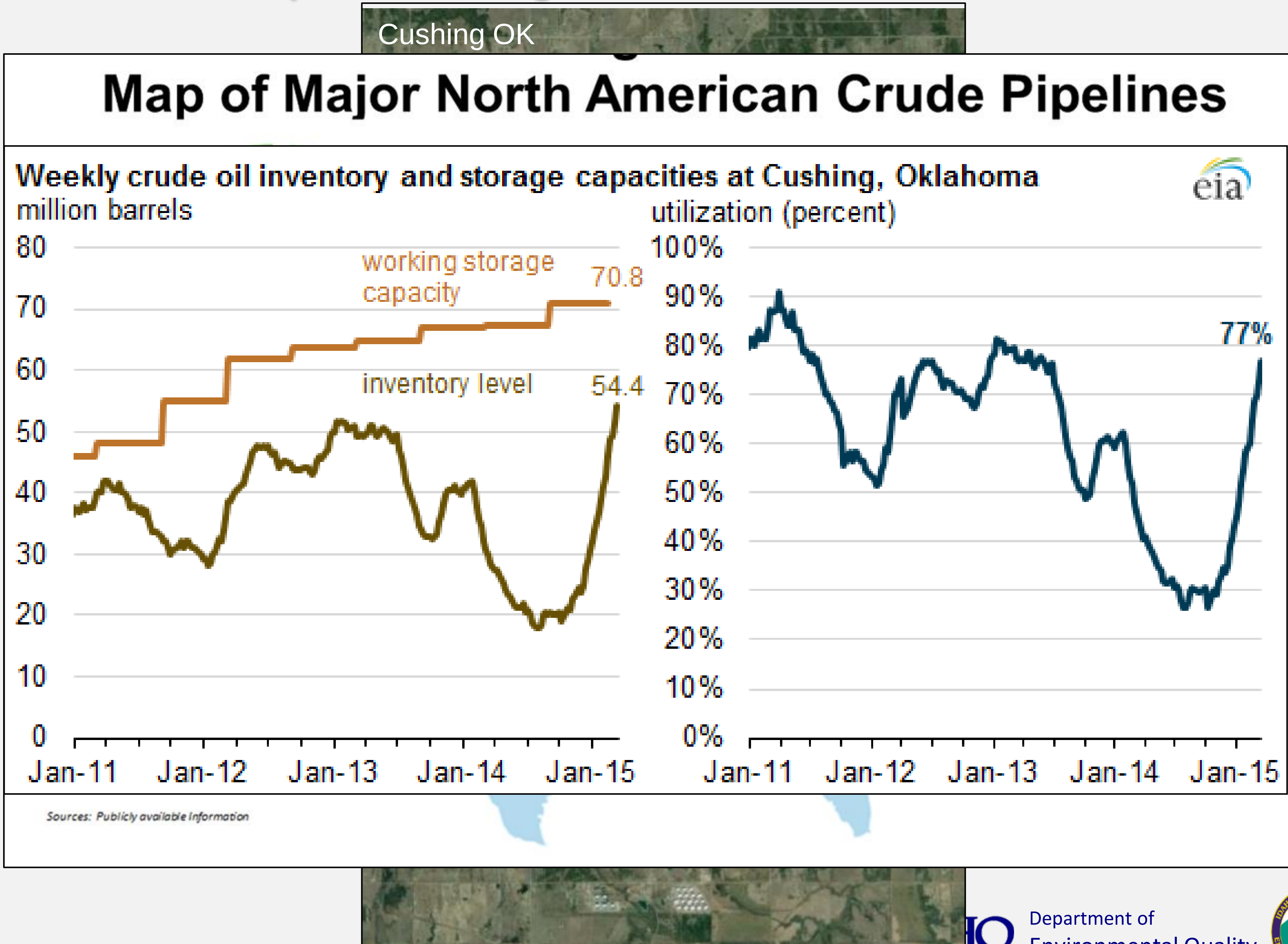


Dakota/US Transport – Dakota Access Pipeline

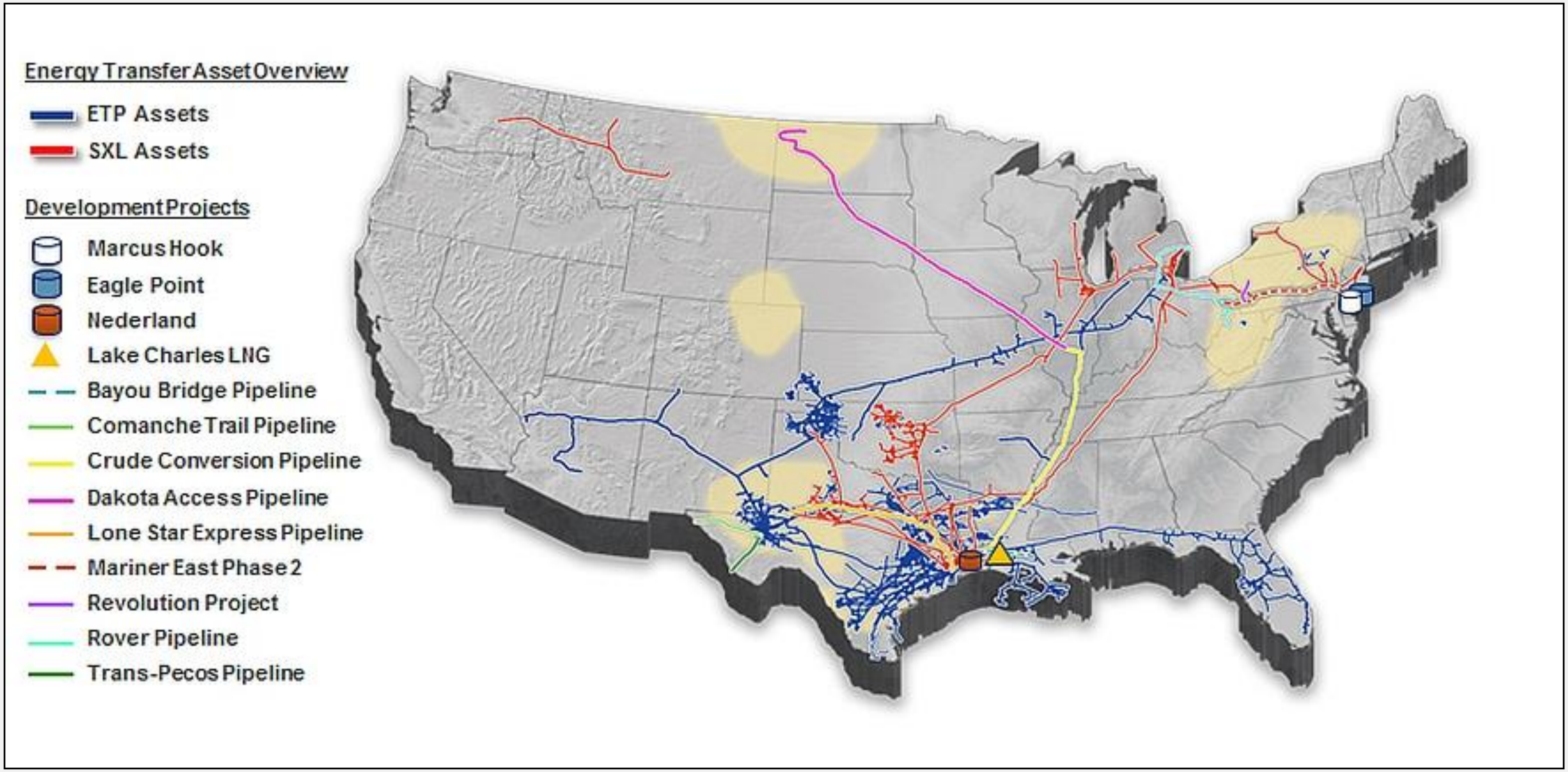


- Will significantly reduce truck and rail transport
- Completion by end of 2016

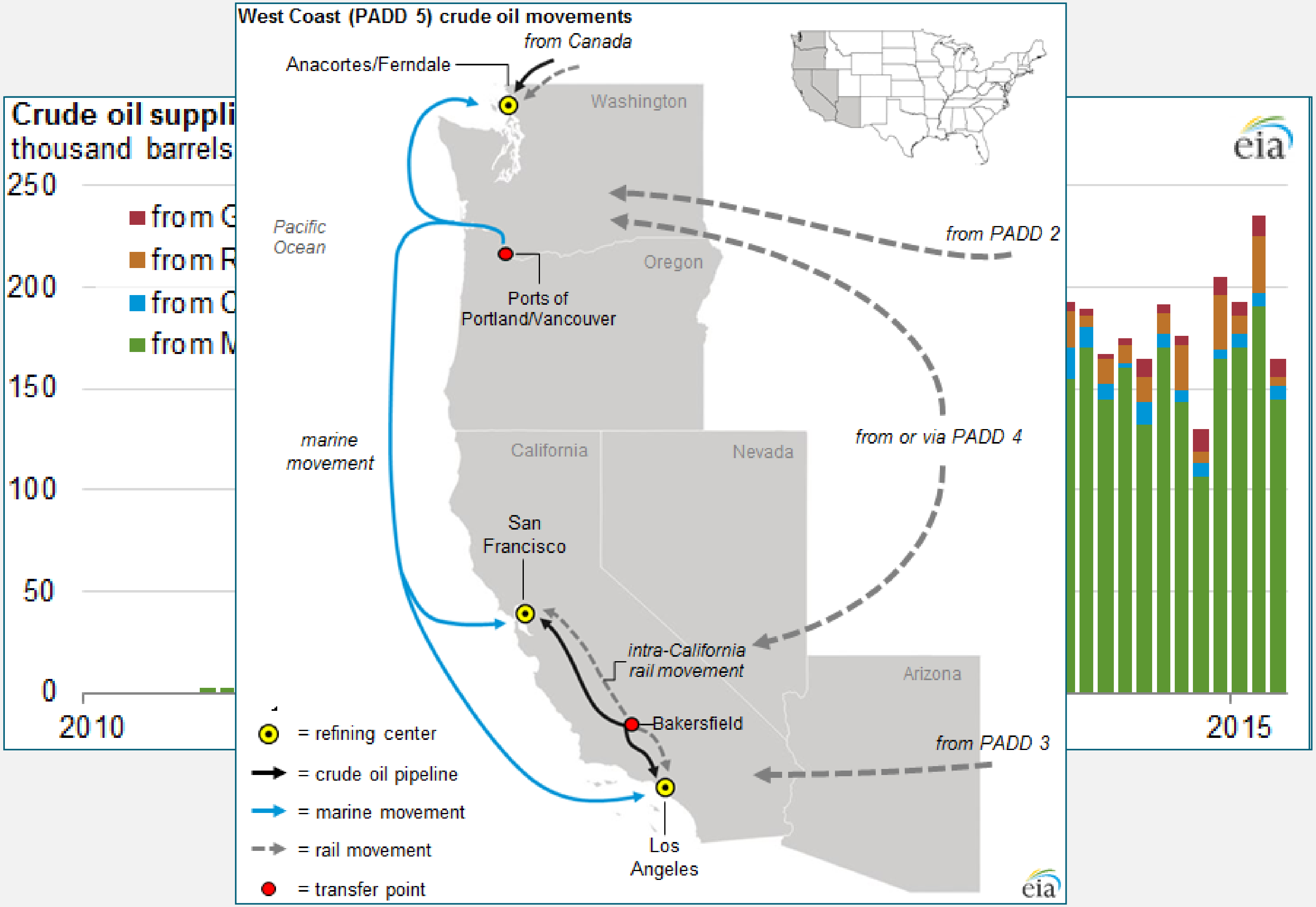
Dakota/US Transport – Cushing Oil Terminal



Dakota/US Transport – West Coast



Dakota/US Transport – West Coast



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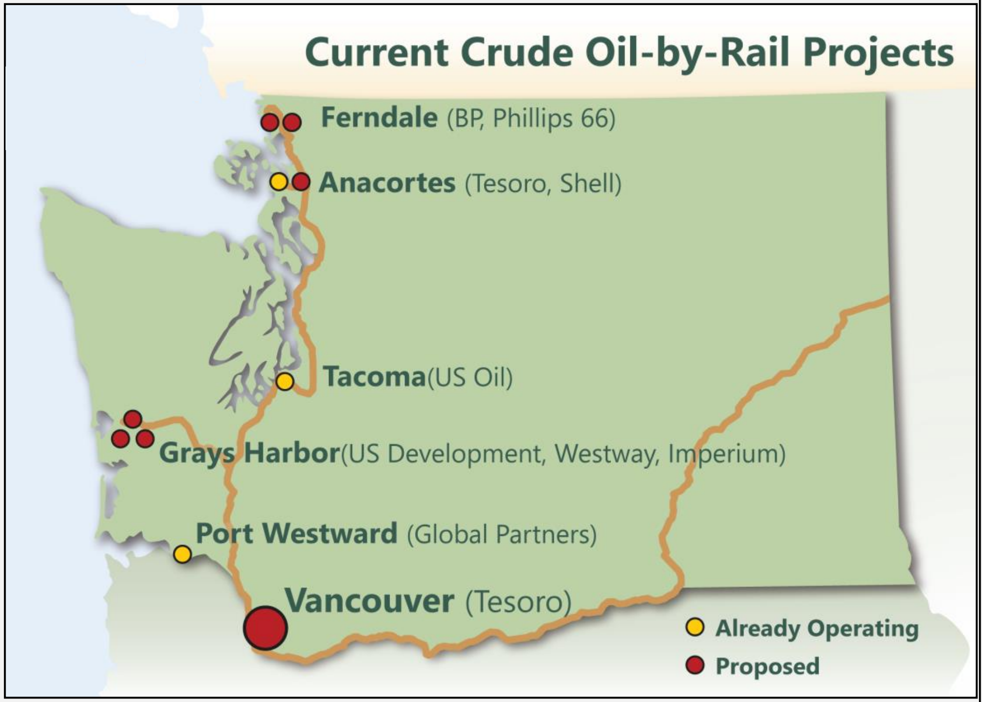
Dakota/US Transport – West Coast



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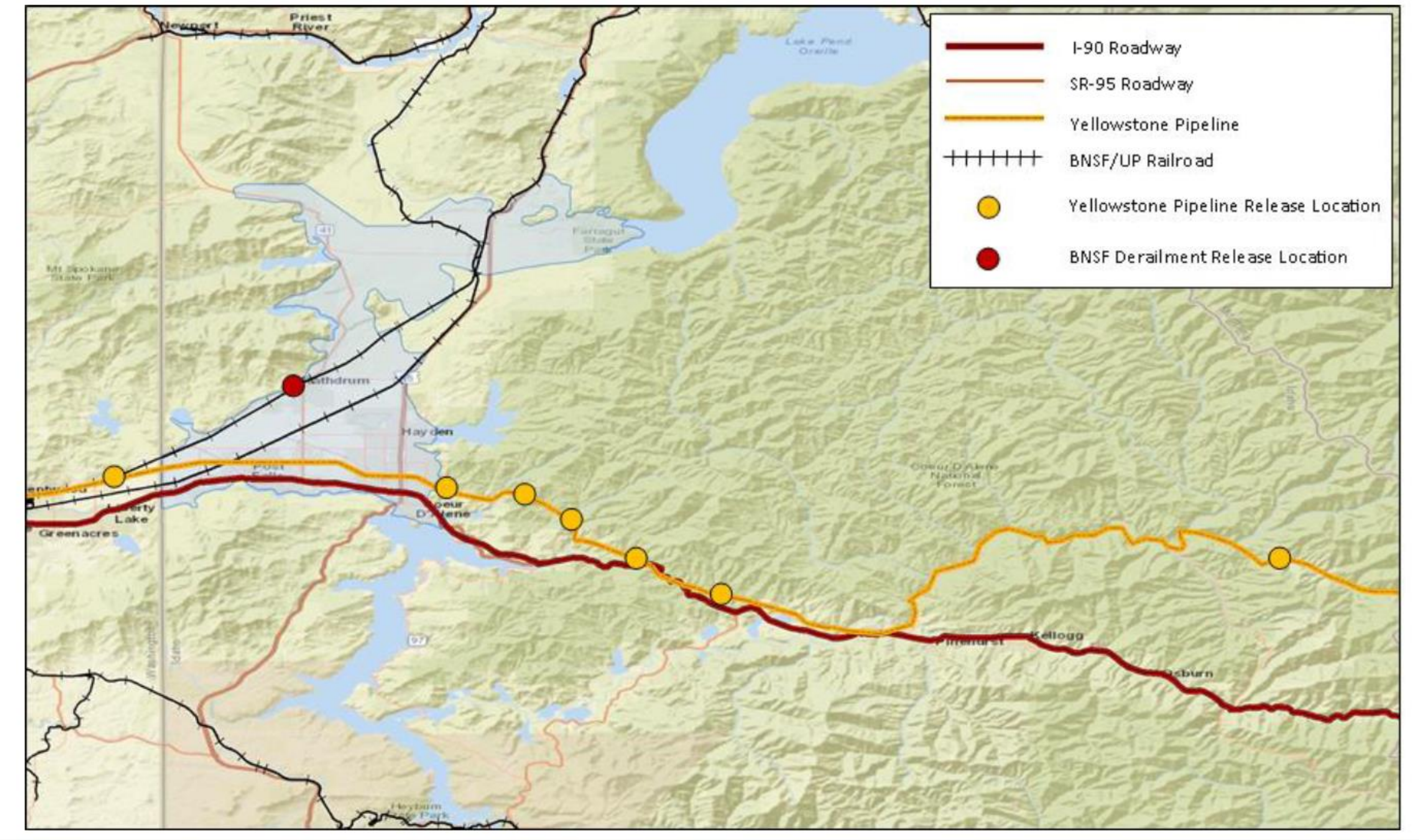
Historical Releases



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Historical Releases – BNSF Hauser

- Derailment Feb. 2001 approx. 2 miles Northeast of Hauser
- Cause- Damaged tread on car
- 28 railcars on two trains derailed, including seven railcars containing Fuel Oil #5.
- Approximately 3,000 gal of Fuel Oil #5 released
- 900 cubic yards of soil removed

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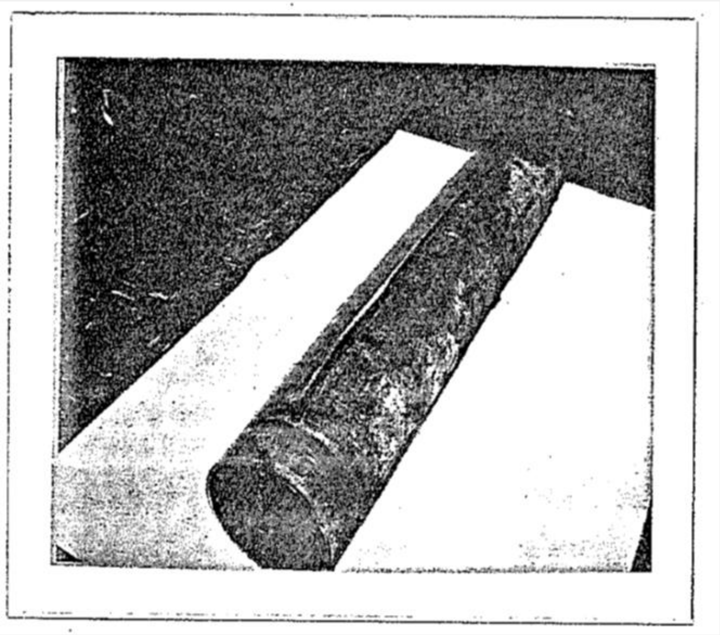
Historical Releases – Yellowstone Pipeline

Yellowstone Pipeline Releases in ID and WA over the SVRP

Release Date	Location	Release Volume (gallons)	Substance Released	Cause
September 15, 1954	20 miles east of Coeur d'Alene	69,678	Gasoline	Dozer blade punctured pipeline
April 10, 1955	East of Coeur d'Alene	193,872	Diesel	Tractor crossing over pipeline
October 16, 1965	5 miles east of Coeur d'Alene	43,848	Diesel	Gunshot perforated pipeline
May 2, 1973	Near Murray , Idaho	169,302	Diesel	Pipe split - approximately 50 in. long
May 4, 1983	8 miles east of Coeur d'Alene	24,948	Gasoline	Pipe impacted while removal of gravel for bridge construction
July 23, 1987	Near I-90 Fourth of July Pass	27,048	Various	Grader widening forest service road cut into pipeline
October 23. 1996	Spokane Valley	Unknown	Unknown	Pinhole perforation found in pipeline during inspection



Historical Releases – United States

Train Derailments with remedial impacts and volumes

Location	Release Date	Material	Estimated Oil Release To Surrounding Area (gallons)	Estimated Oil Burned Volume (gallons)	Estimated Excavated Soil (yds^3)	Groundwater Contamination	Surface Water Contamination	Fire
Lac Megantic, QB	7/5/2013	Bakken Crude	1,505,780	4,494,220	366,226	No	Yes	Yes
Casselton, ND	12/30/2013	Bakken Crude	400,000	NA[1]	7,479	Yes	No	Yes
Galena, IL	3/5/2015	Bakken Crude	110,543	94,929	1,304	Yes	Yes	Yes
Heimdal, ND	5/6/2015	Bakken Crude	94,000	34,000	1,929[2]	No	No	Yes
Culbertson, MT	7/16/2015	Bakken Crude	27,210	0	3,925	Yes	No	No
Rathdrum, ID	2/27/2001	Fuel Oil #5	3,000	0	900	No	No	No

[1] Volume not calculated but a significant volume of crude oil was reported have been consumed in the fire.

[2] 2,439.39 tons with density of 1.5 g/cc

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Petroleum Properties

Density – Crude oil measured in API units (gravity degree), Gasoline in grams per cubic centimeter.

Light crude oil > 31° (< 0.87 g/cc)
Heavy crude oil < 31° (> 0.87 g/cc)
Bakken Crude = 40° to 43° (0.81 to 0.83 g/cc)
Gasoline = 0.73 to 0.75 g/cc

Sulfur Content < 0.5% by weight = Sweet
> 0.5% by weight = Sour
Bakken Crude = 0.1% by weight
Gasoline = regulated by EPA at 30 ppm (0.0% by weight)

Dynamic Viscosity – Liquids resistance to shear stress or flow (centipoise)
Water = 1.0 cp
Motor Oil (SAE 40) = 250 cp
Bakken Crude = 2.7 cp
Gasoline = 0.37 to 0.45 cp

Interfacial Tension – Measure of adhesive force between oil and water (dynes/cm)
Oil/Water = 18.0 to 29.5 dynes/cm
Bakken Crude = 18.4 dynes/cm
Gasoline = 49 to 51 dynes/cm

Petroleum Properties

Reid Vapor Pressure – Pressure exerted in a closed container by the vapor from the crude oil that has obtained equilibrium at 100° F.

Bakken Crude Oil contains methane, propane, butane and pentane.

RVP provides a bulk measurement of volatiles.

The greater the RVP the greater the volatile content

1 = Hanger strap
2 = Pressure gauge
3 = Vapor chamber
4 = Threaded connection
5 = Liquid chamber

Entire assembly is immersed in electrically heated water bath.

Petroleum Properties

- North Dakota Industrial Commission requires conditioning at the well site to remove volatiles for safer transport (Order No. 25417, effective April 1, 2015)
- ANSI/API RP 3000 (Classifying and Loading of Crude Oil into Rail Tank Cars) defines stable crude oil as having a vapor pressure equal to or less than 14.7 psi (one atmosphere).
- Will not boil at room temperature
- Equipment that test for vapor pressure has a margin of error of 1.0 psi so Industrial Commission chose **13.7 psi**.
- Cost approximately $0.10 to $0.20 per barrel, or $120,000 to $240,000 per day based on 1.2 million barrels per day production

Galena, IL Mar. 05, 2015

Casselton, ND Dec. 30, 2013

Bakken Crude Oil – Range 3.6 to 15.4 psi
Average 10.4 psi
80% of Bakken Crude < 11.8 psi

Lac Megantic, QB – RVP 9.0 to 9.5 psi
Mosier, OR – RVP 9.2 psi
Gasoline - EPA mandated RVP 7.8 to 9.0 psi

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Petroleum Properties

Crude Name	Origin	API	RVP (psia)	Vol % of Light Ends (C2 – C5)
Arabian Super Light	Saudi Arabia	51	20.7	12.53 wt %[25] (C1-C4 only)
Eagle Ford	Texas	48	7.95	8.3
Agbami	Nigeria	48	2.2	5.61 wt %
DJ Basin	Colorado	45	7.82	8.0
Sarahan Blend	Algeria	43	7.46	8.1
Bakken	North Dakota	42	7.83	7.2
WTI	Texas / New Mexico	41	5.90	6.1
Brent[26]	United Kingdom	37.5	9.33	5.28 wt %
API gravity of 37 or more defines light crude oil		37		
LLS	Louisiana	36	4.18	3.0
Alvheim blend	Norway	34.9	3.9	1.86 wt %
Arabian Heavy	Saudi Arabia	28.4	18.3	5.13 wt % (C1-C4)
Alberta Dilbit[27]	Alberta	21.1	7.18	7.30 wt %
Alba	United Kingdom	19.6	1.6	0.14 wt %

Casselton, ND

American Fuel & Petrochemical Manufacturers,2014

Fate & Transport Models

Purpose: Evaluate three idealized release scenarios using a subsurface with representative conditions

R.R. Tanker – Instantaneous & high volume release rate

Tanker Truck – Instantaneous & high volume release rate

Pipeline Release – Long term & low volume release rate

Casselton

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Fate & Transport Models

- Multispecies Oil Fate and Transport (MOFAT)
- Created by EPA 1991
- Written in Fortran
- Two –Dimensional Finite Element Program
- Cannot exceed 1,500 nodes
- Models LNAPL & DNAPL in the unsaturated zone
- Limited documentation and no technical support
- Must run in virtual XP machine
- Commonly used model for fate & transport of NAPL in unsaturated zone
- Can model complex scenarios

PB91-191692

EPA/600/2-91/020
May 1991

MOFAT:
A TWO-DIMENSIONAL FINITE ELEMENT PROGRAM
FOR MULTIPHASE FLOW AND MULTICOMPONENT TRANSPORT

Program Documentation and User's Guide

by

A. K. Katyal, J. J. Kaluarachchi and J. C. Parker
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Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0404

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ADA, OKLAHOMA 74820

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SPRINGFIELD, VA 22161

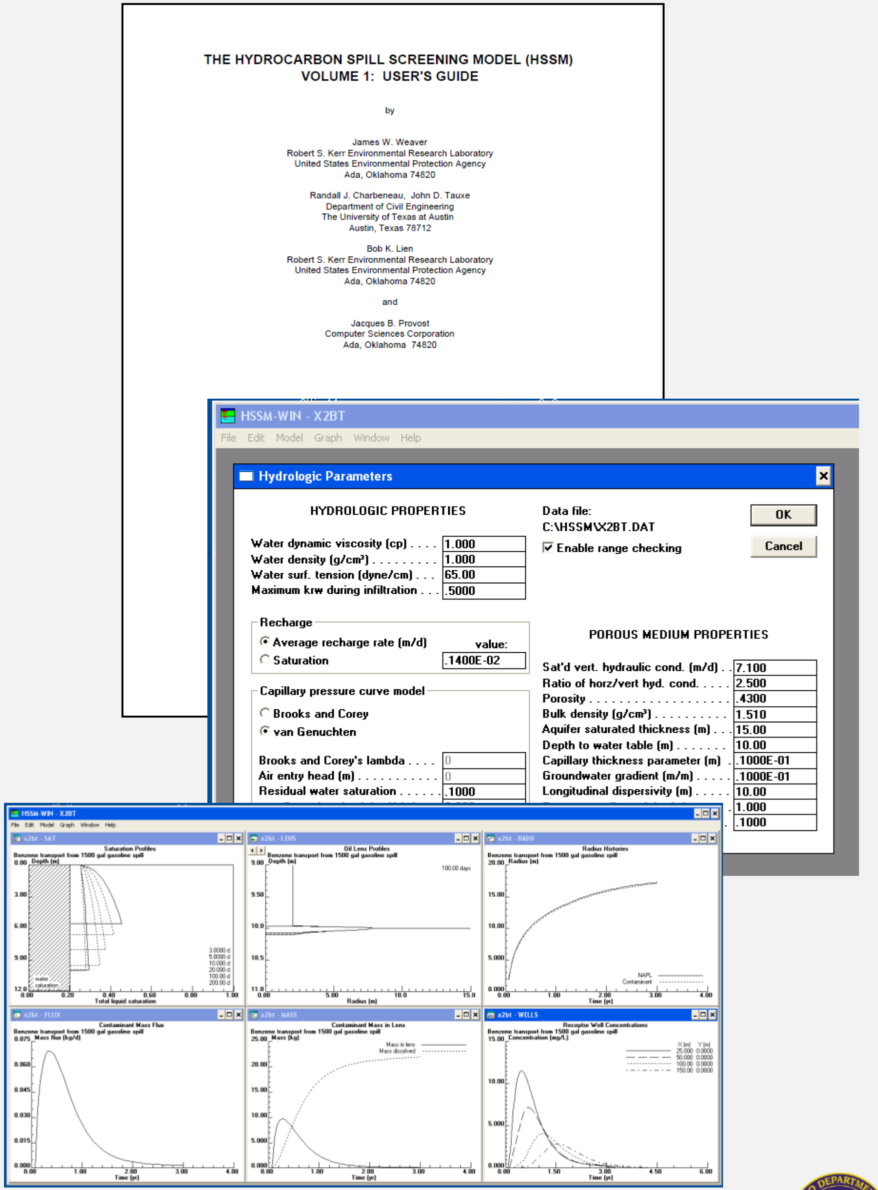
MOFAT for Windows

- Created by Draper Aden 1996
- Pre- and Post Processor, mesh editor
- No documentation or technical support
- Must run in virtual XP machine
- Output used in Surfer to construct 2D Contours

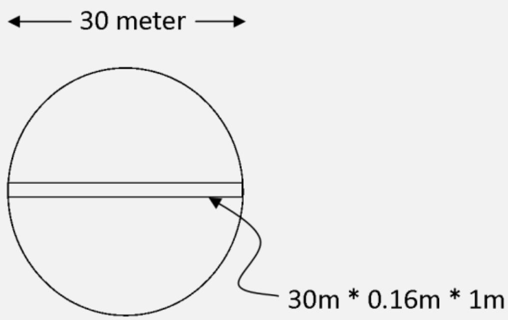
Fate & Transport Models

<u>Hydrocarbon Spill Screening Model (HSSM)</u>

- Created by EPA 1994
- Series of Analytical Solutions
- Models NAPL in the unsaturated and saturated zone (modeled benzene)
- One Dimensional in Unsat and Two-Dimensional in Saturated
- Upper bound to hydraulic conductivity
- Good GUI
- Good documentation and limited technical support
- Must run in virtual XP machine
- Commonly used model for fate & transport of NAPL in unsaturated & saturated zone
- Can model simple scenarios



Fate & Transport Models



Scenario #1 Fixed volume release of crude oil (MOFAT Only)

<u>Calculated depth</u>

30,000 gallons = 113.6 cubic meters

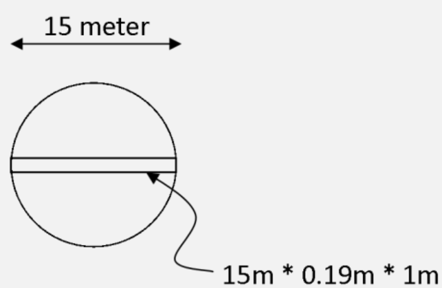
Area = $\pi r^2 = 3.14 * (15m)^2 = 706.9\ m^2$

Depth = $113.6\ m^3 / 706.9\ m^2$

Depth = 0.16 meters = 6.3 in

<u>2D Model Infiltrated Volume</u>

30m * 0.16 m * 1m = 4.8 m^3 = 1,268 gal.



Scenario #2 Fixed volume release of gasoline (MOFAT Only)

<u>Calculated Depth</u>

9,000 gallons = 34.1cubic meters

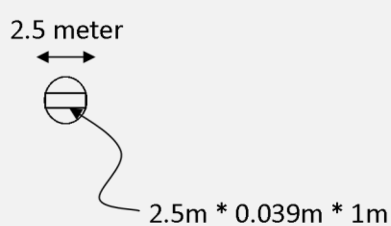
Area = $\pi r^2 = 3.14 * (7.5m)^2 = 176.7\ m^2$

Depth = $34.1\ m^3 / 176.7\ m^2$

Depth = 0.19 meters = 7.5 in

<u>2D Model Infiltrated Volume</u>

15m * 0.19m * 1m = 2.85 m^3 = 753 gal



Scenario #3 Constant rate release of gasoline (MOFAT & HSSM)

<u>Calculated Depth</u>

50 gallons = 0.189 cubic meters

Area = $\pi r^2 = 3.14 * (1.25m)^2 = 4.91\ m^2$

Depth = $0.189\ m^3 / 4.91\ m^2$

Depth = 0.039 meters = 1.5 in

<u>2D Model Infiltrated Volume</u>

2.5m * 0.039m * 1m = 0.098m^3 = 26 gal

Fate & Transport Models

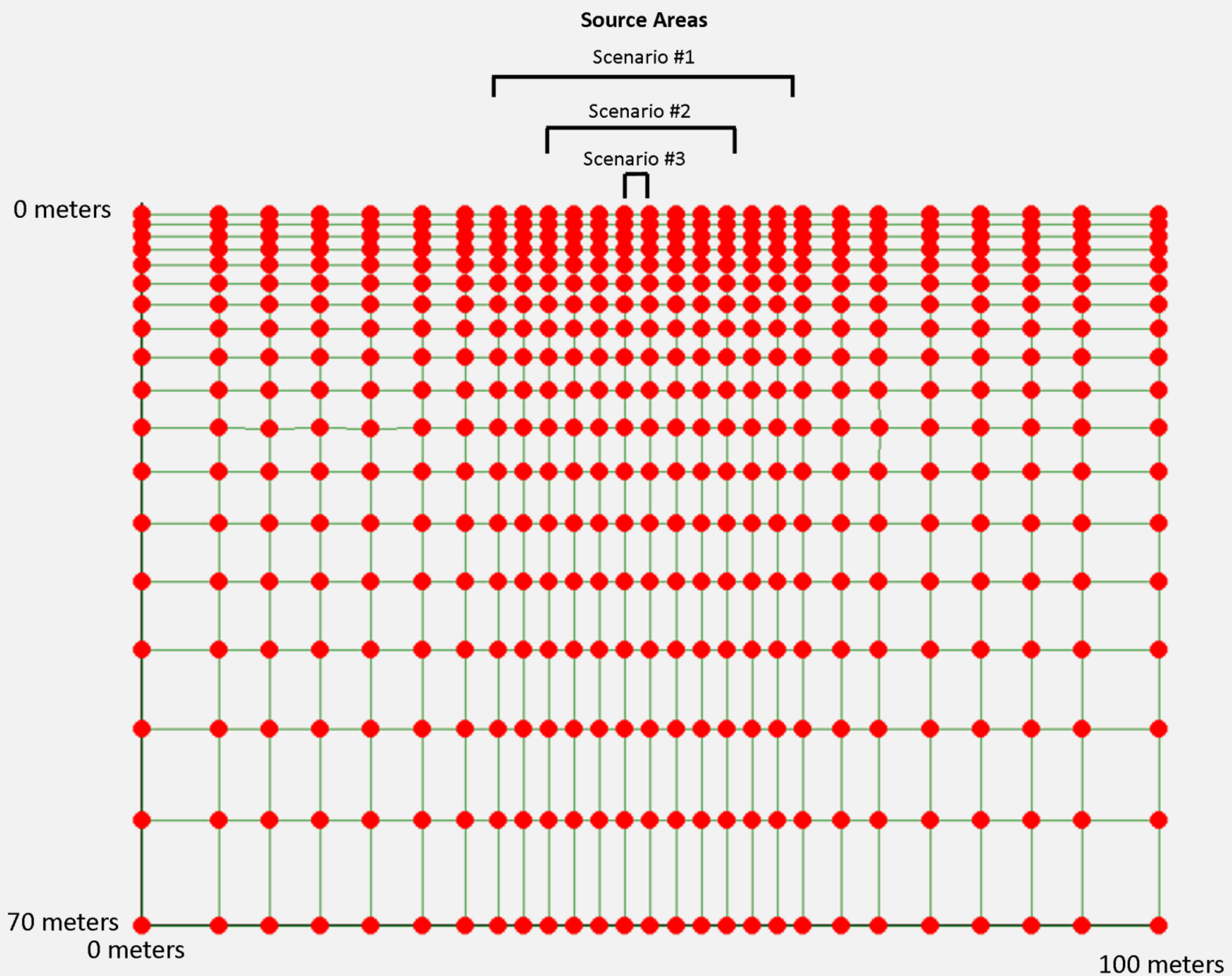
Assumptions:

1. Single Subsurface Unit (No soil)
2. Subsurface is homogeneous and anisotropic (2:1)
3. Hydraulic Conductivity (model restricted)

   MOFAT = 350 m/d horiz., 175 m/d vert.

   HSSM = 500 m/d horiz., 250 md/ vert.
4. Increase gradient in HSSM model to achieve 6.0 m/d (≈ 20 feet/day) saturated velocity
5. Porosity = 0.35
6. Residual Water Saturation = 0.1
7. No other external inputs (precipitation)
8. No evaporation or degradation

Fate & Transport Models – MOFAT Grid



Fate & Transport Models

<u>Variable Hydraulic Conductivity</u>

$$K(\Theta) = K_S \left[\frac{\theta}{\theta s}\right] \quad \text{(Campbell Equation)}$$

K_Θ = Unsaturated Hydraulic Conductivity
K_S = Saturated Hydraulic Conductivity
Θ = percent saturation
Θ_S = percent fully saturated

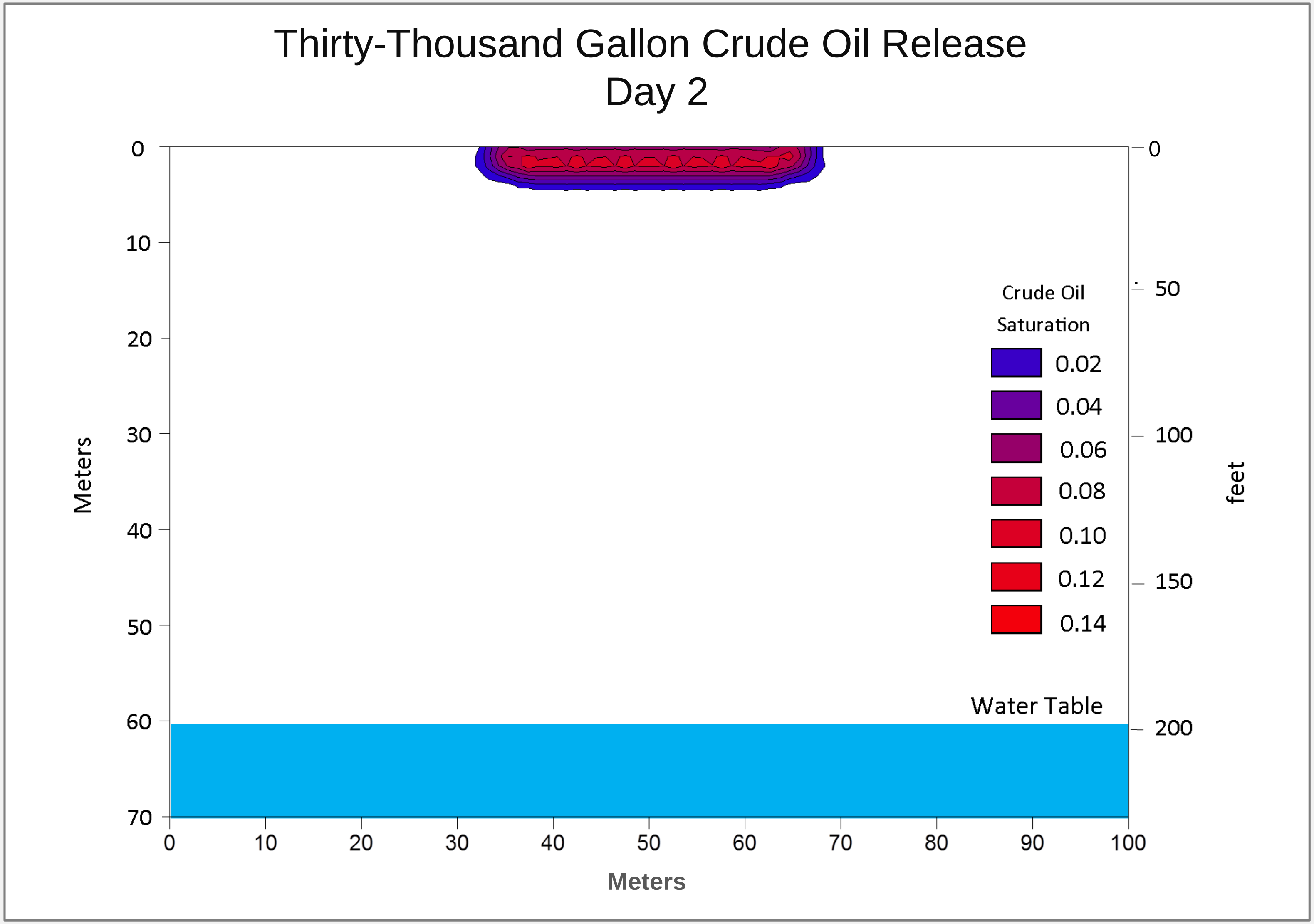
The greater the degree of saturation the greater the hydraulic conductivity
The lower the degree of saturation the lower the hydraulic conductivity

<u>Residual NAPL Saturation</u>

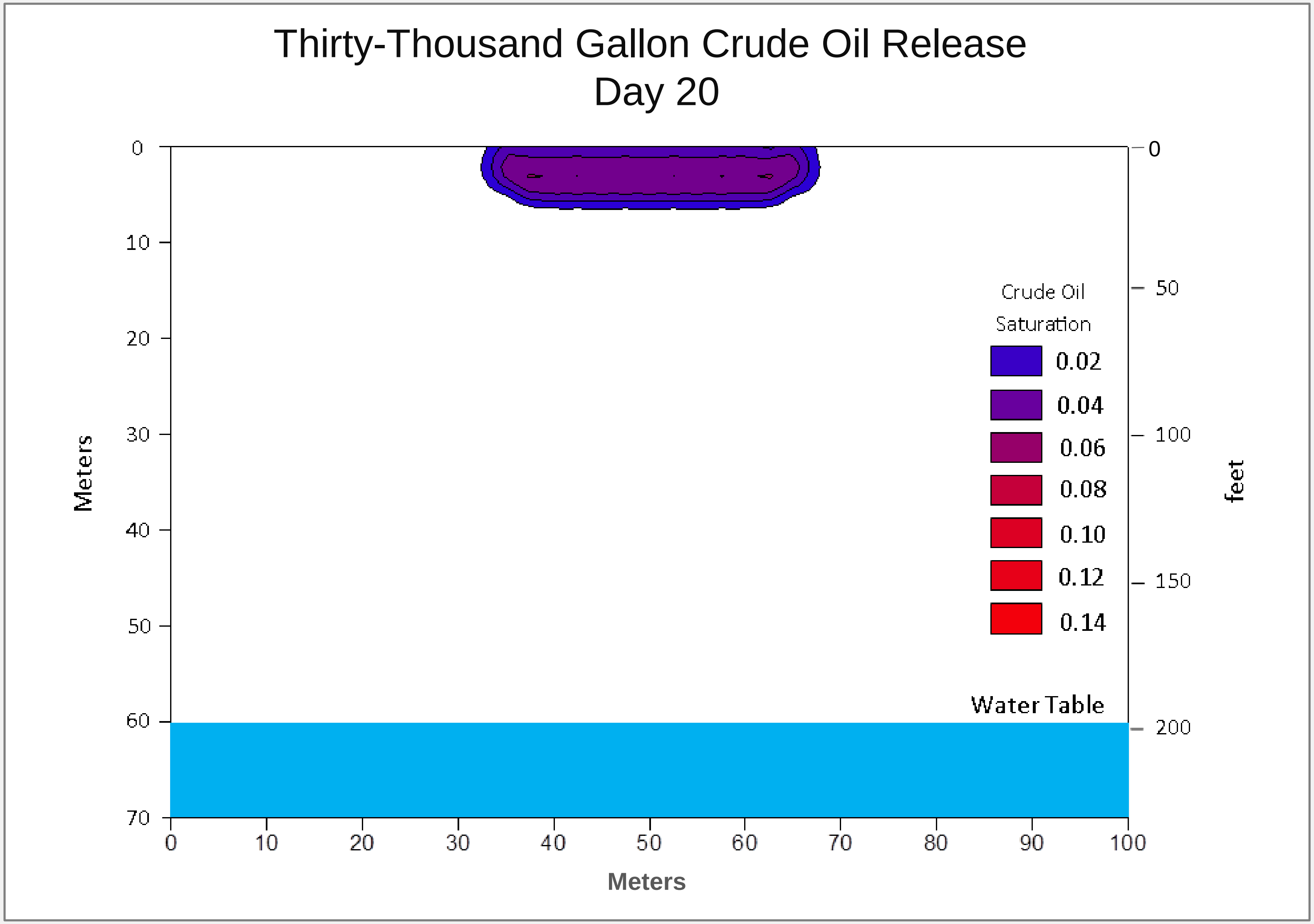
Once the NAPL saturation falls below the residual level the movement of NAPL will cease.

Values Range between 0.02 – 0.20

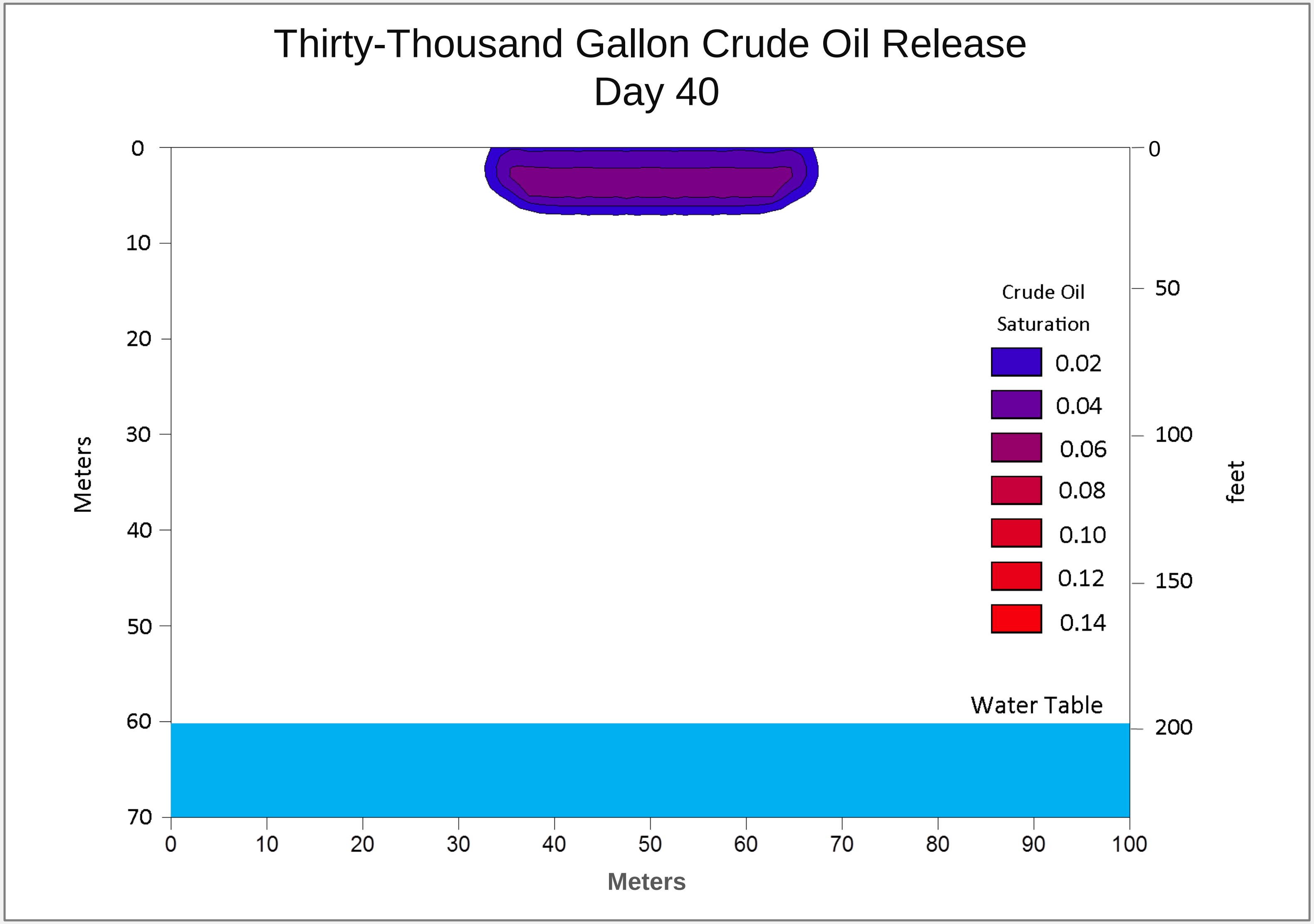
Fate & Transport Models



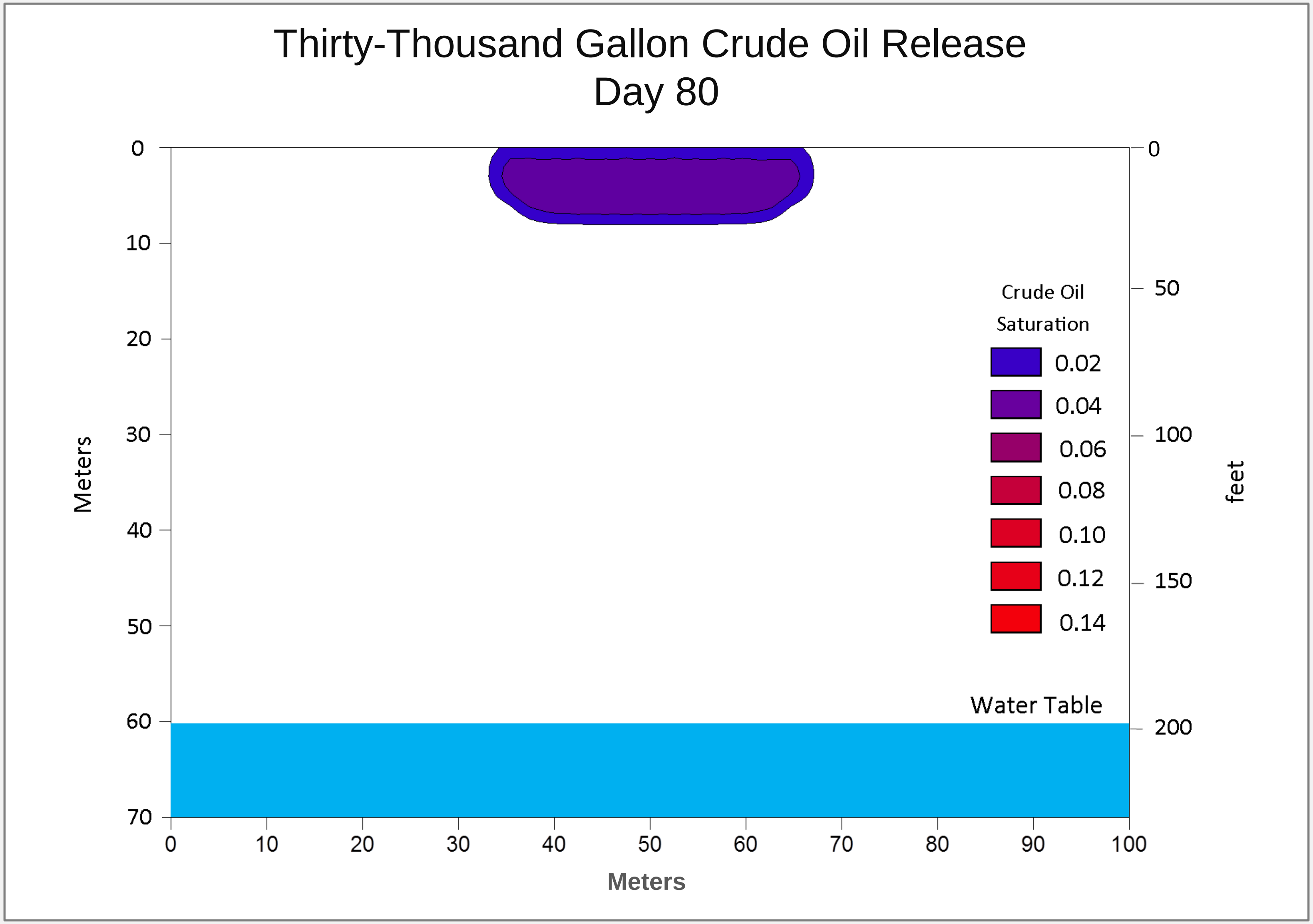
Fate & Transport Models



Fate & Transport Models



Fate & Transport Models



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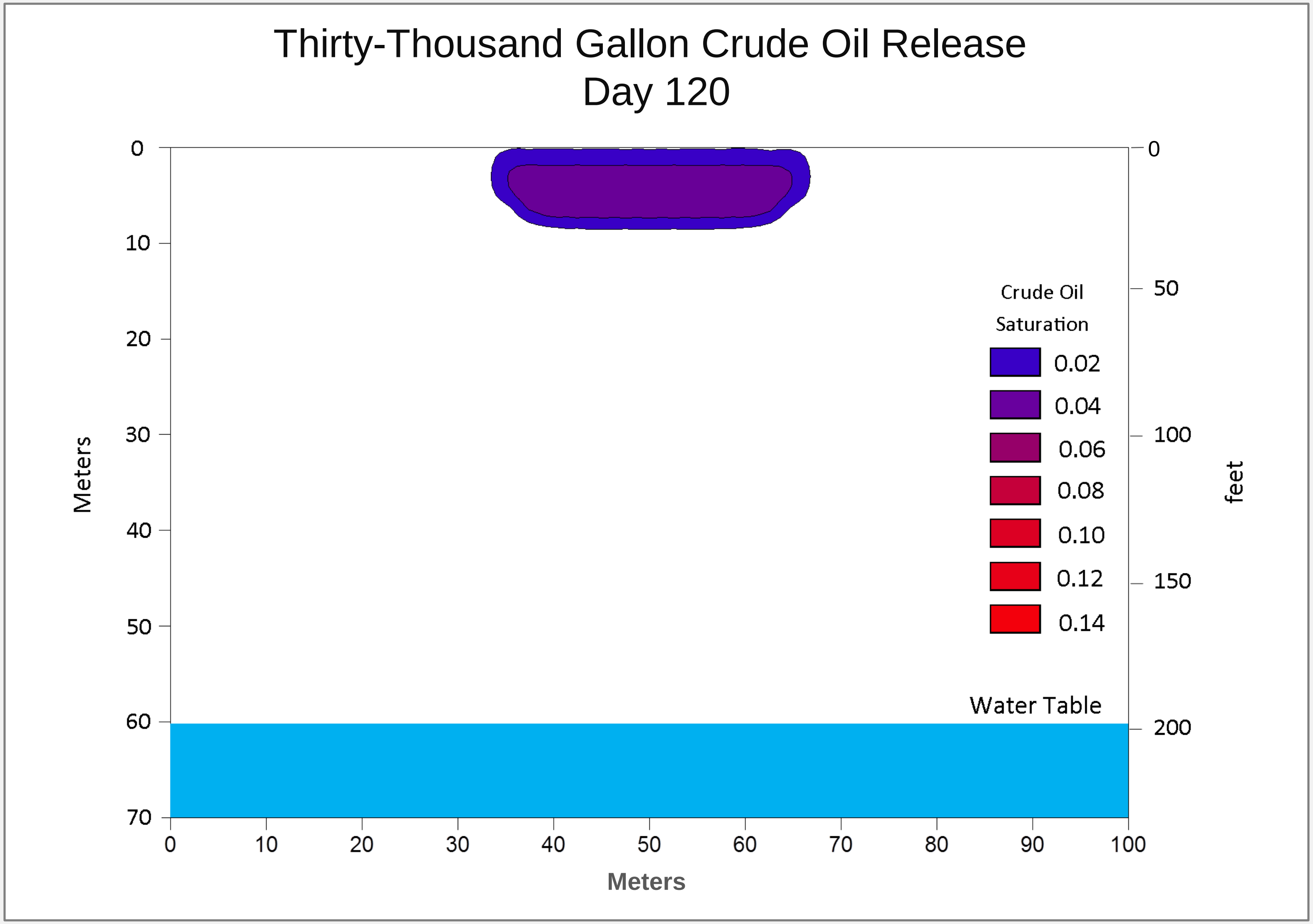
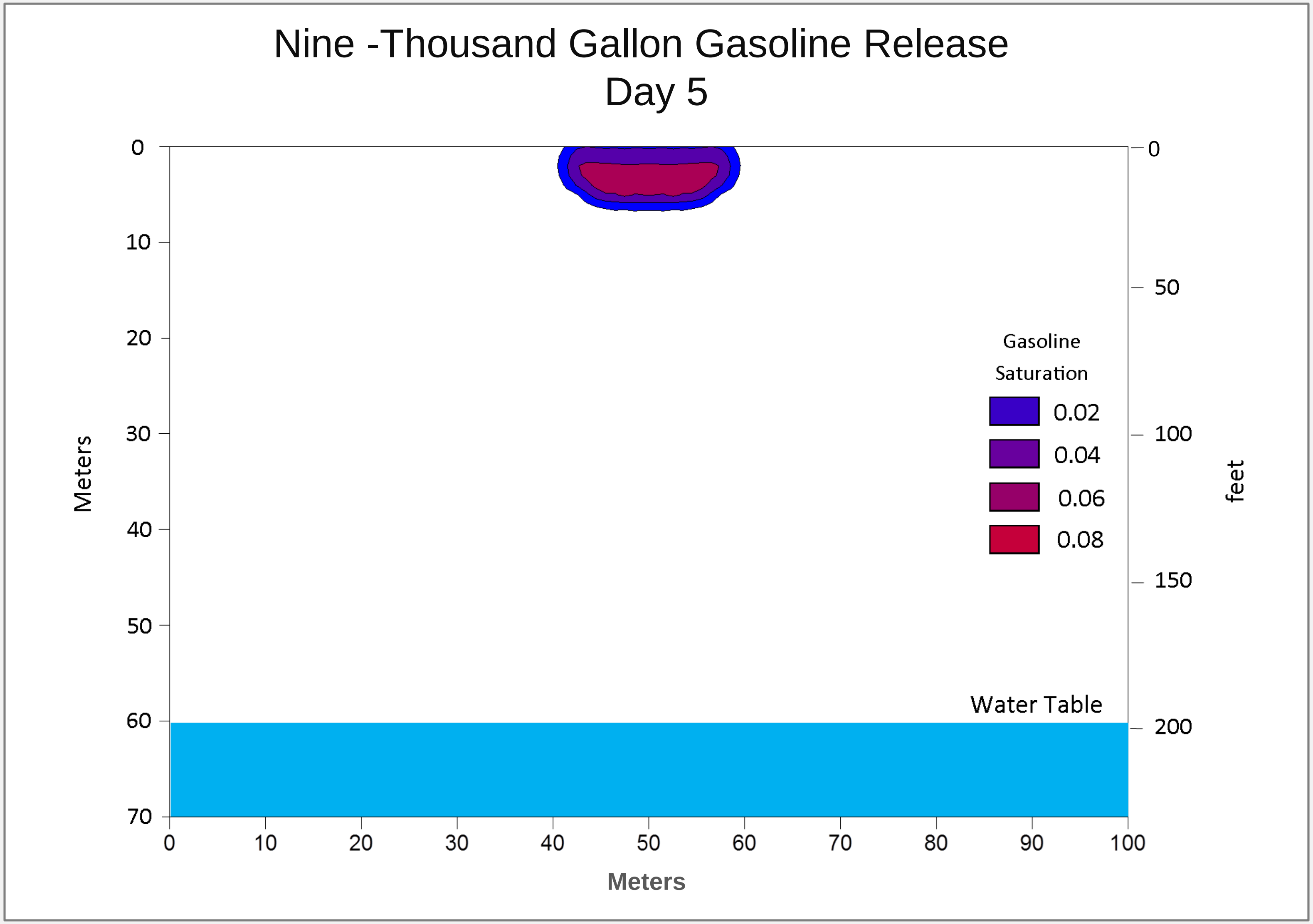
Fate & Transport Models



Fate & Transport Models



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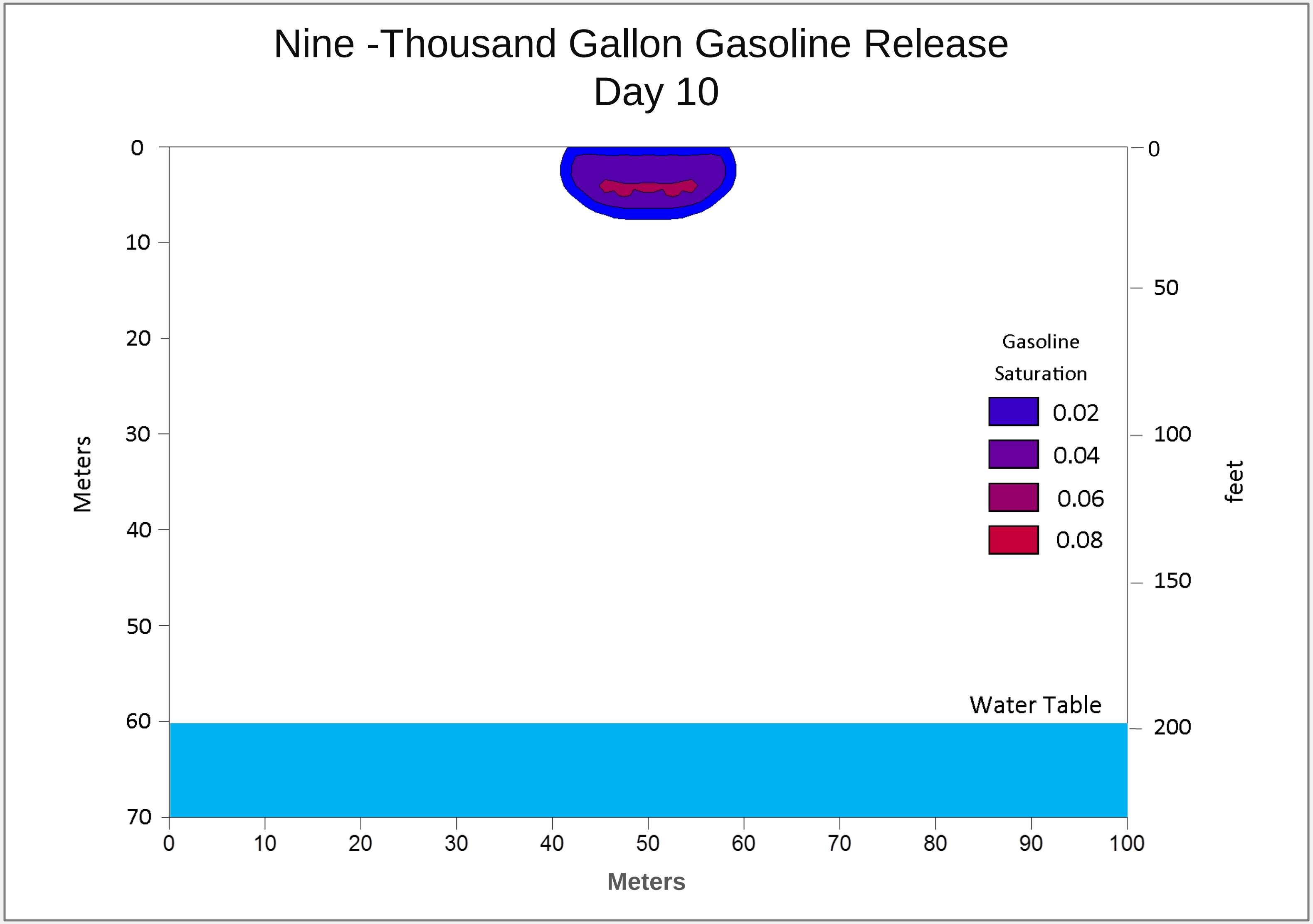
Fate & Transport Models



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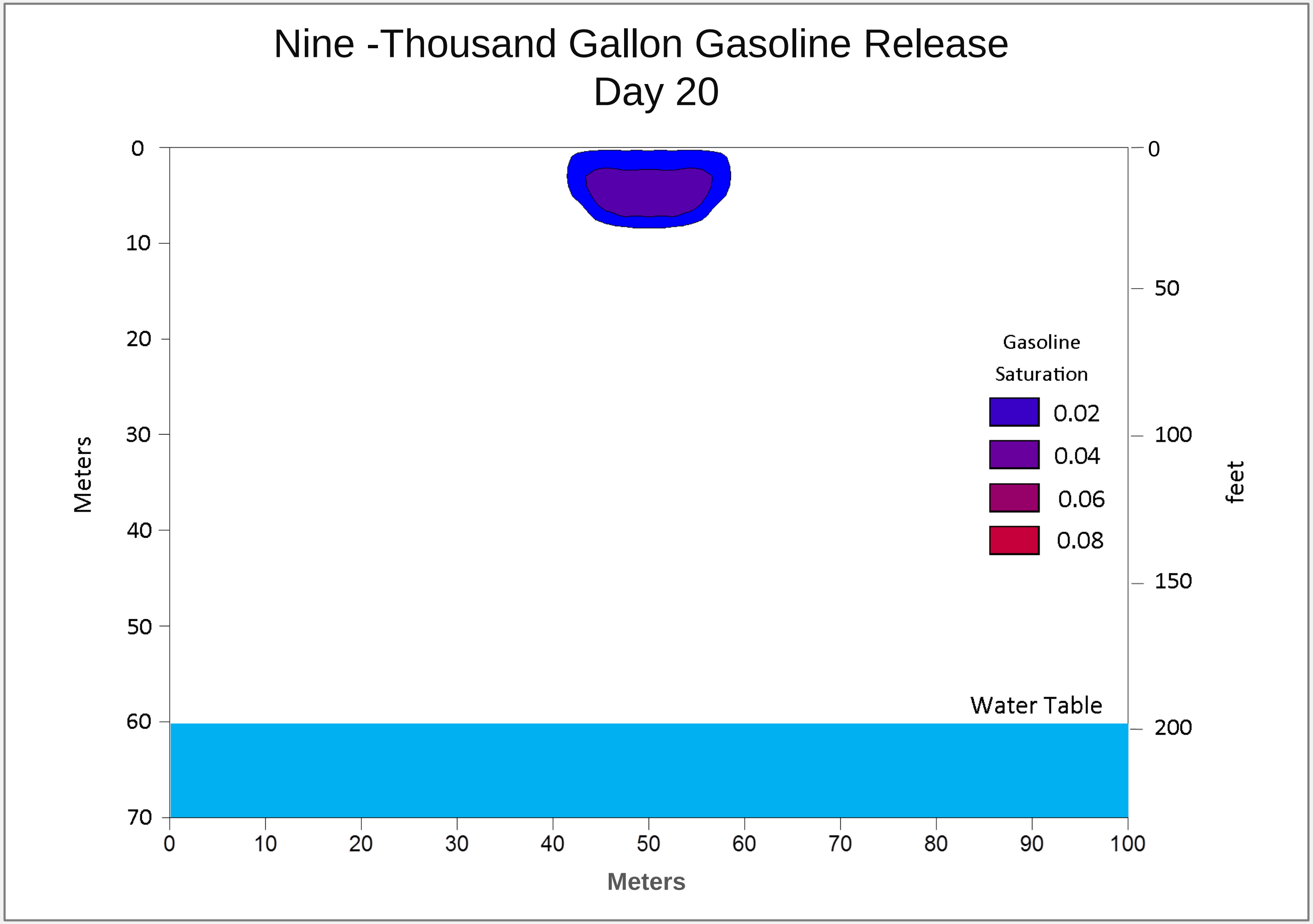
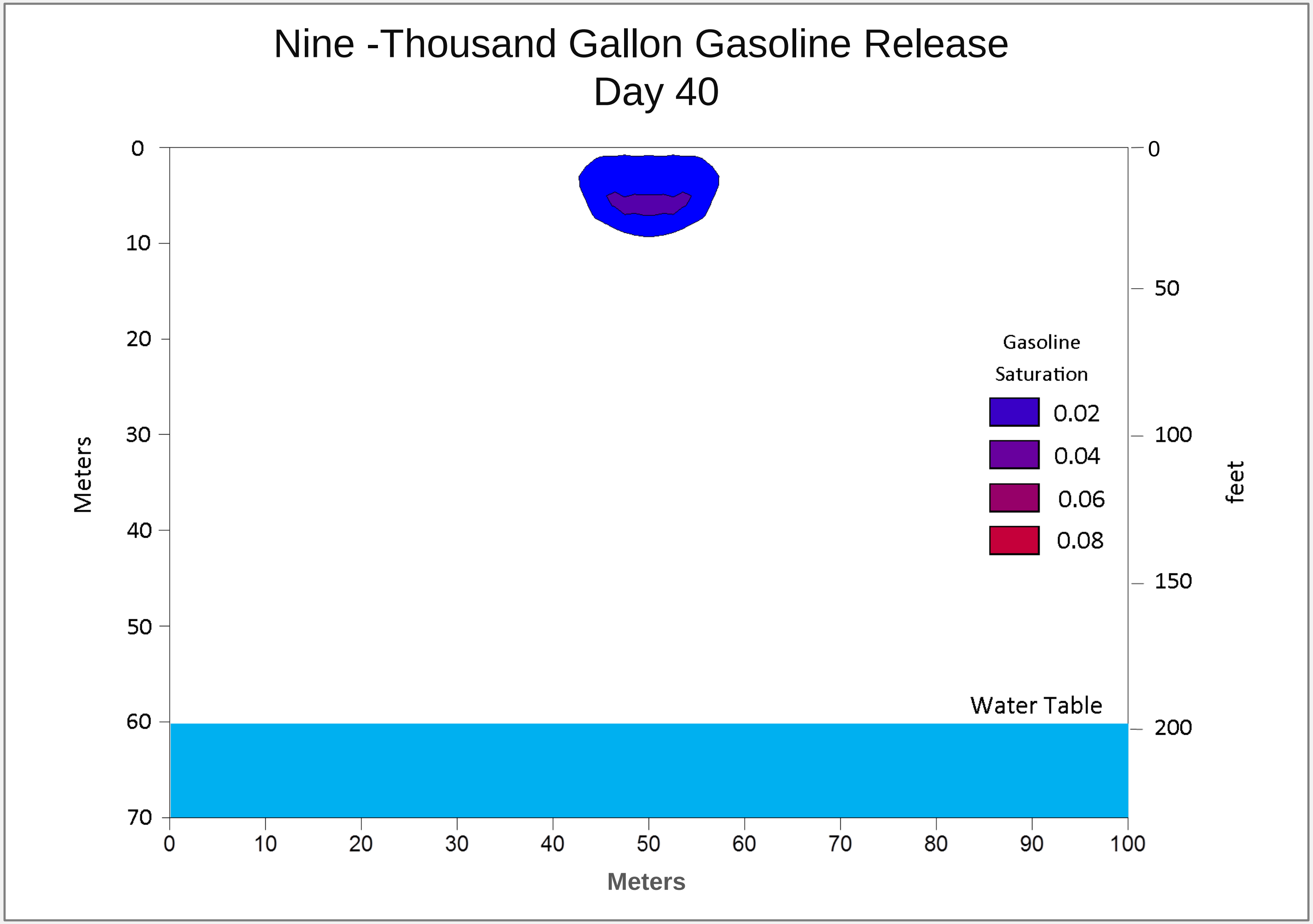


Fate & Transport Models



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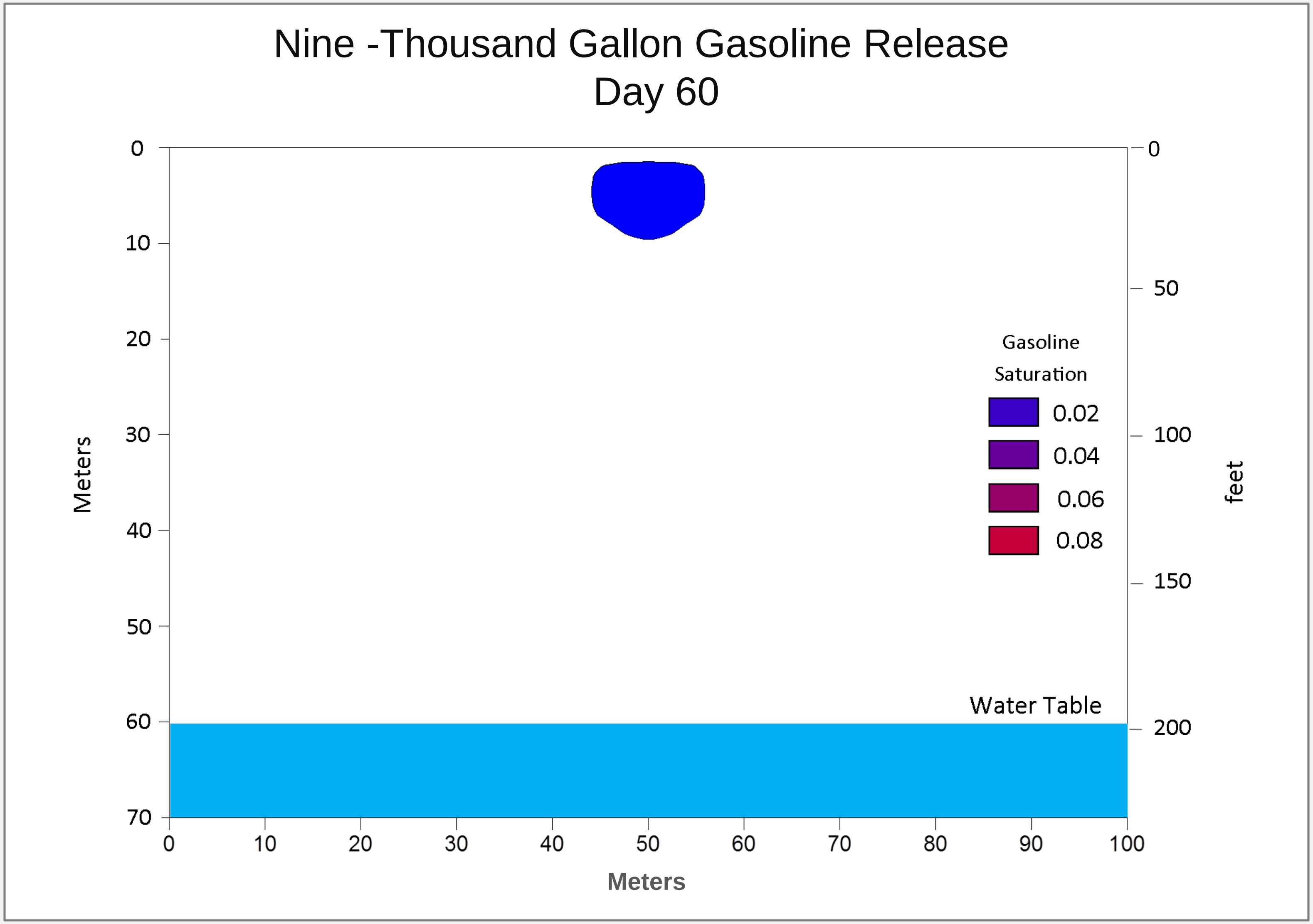

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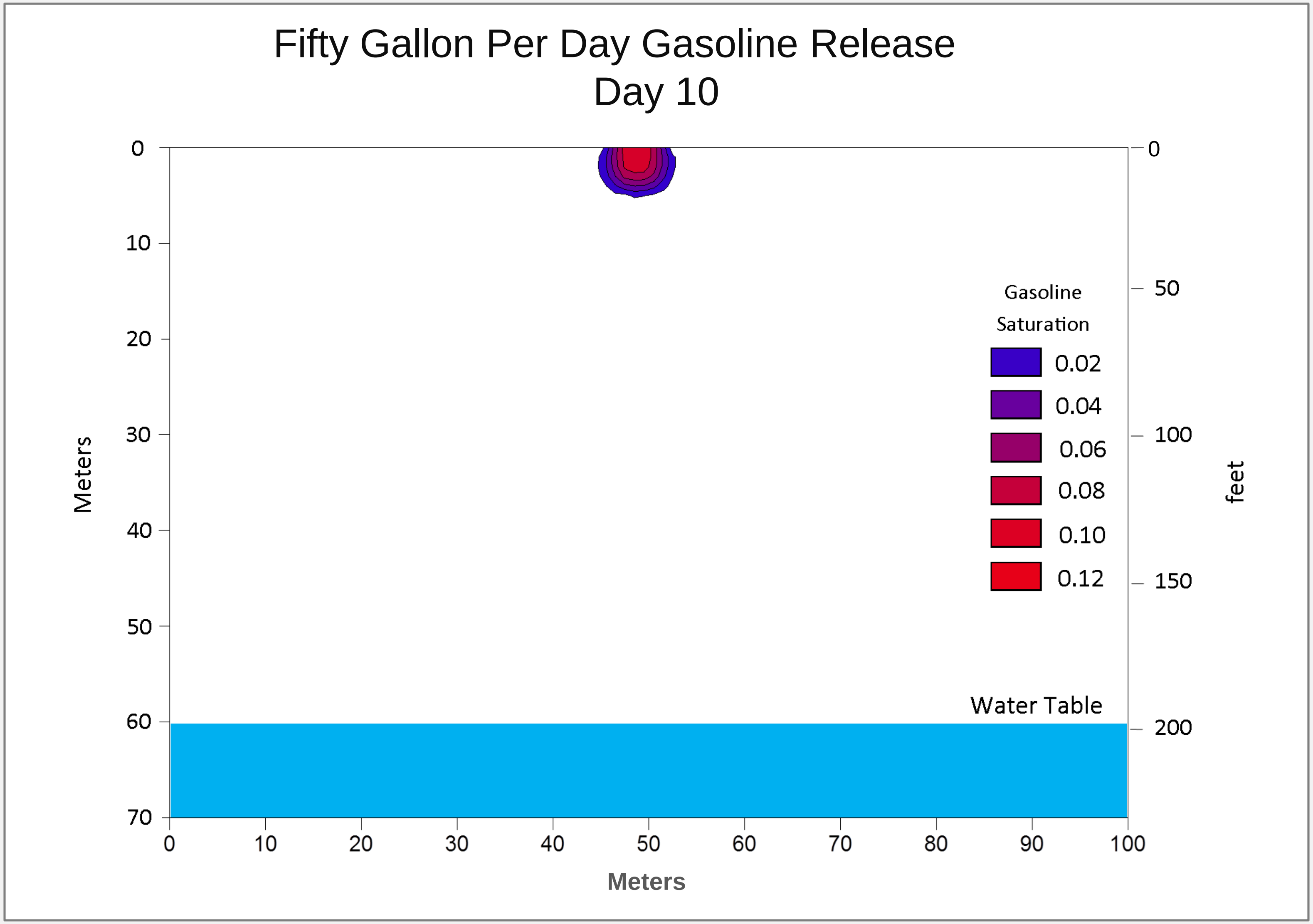

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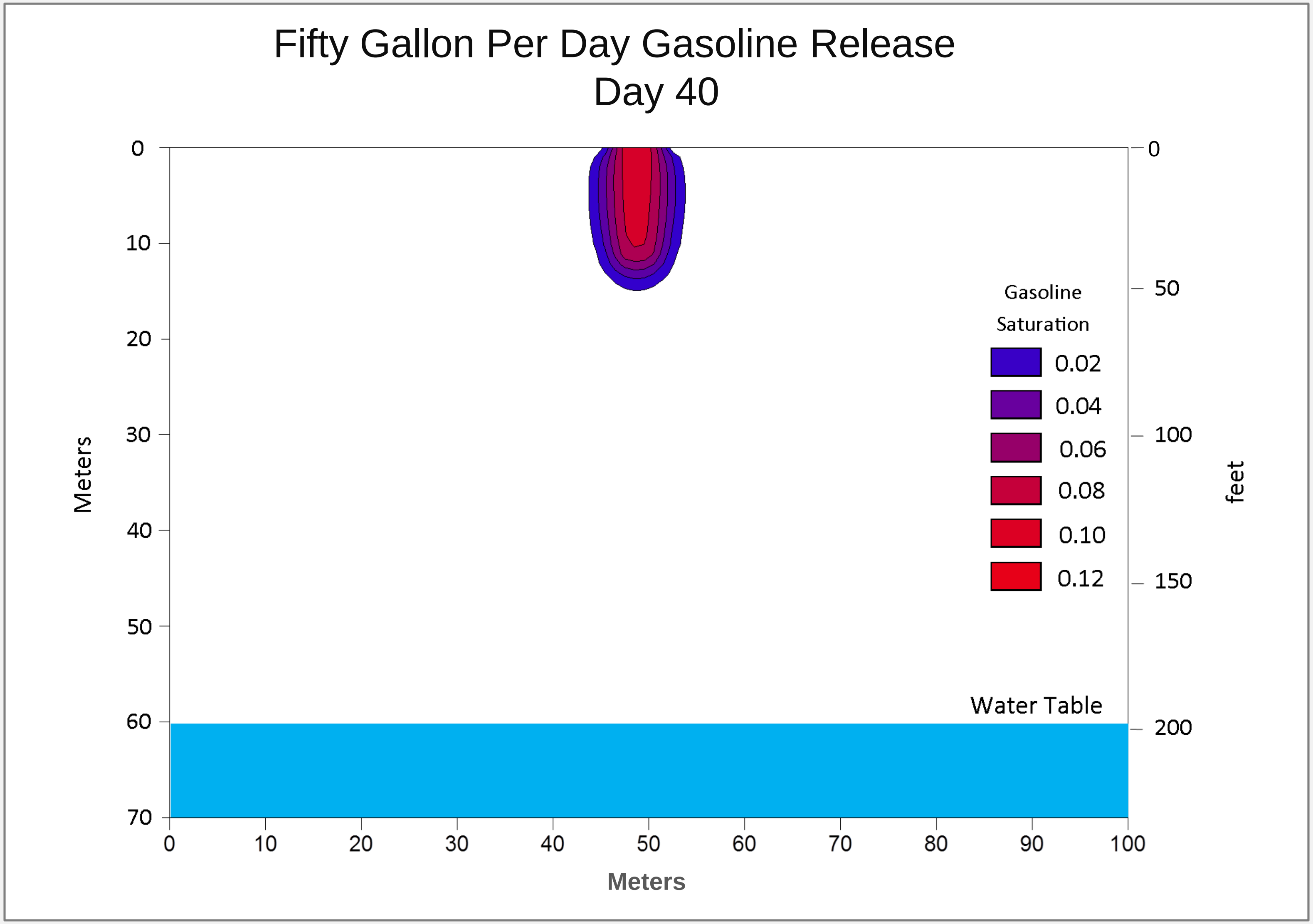

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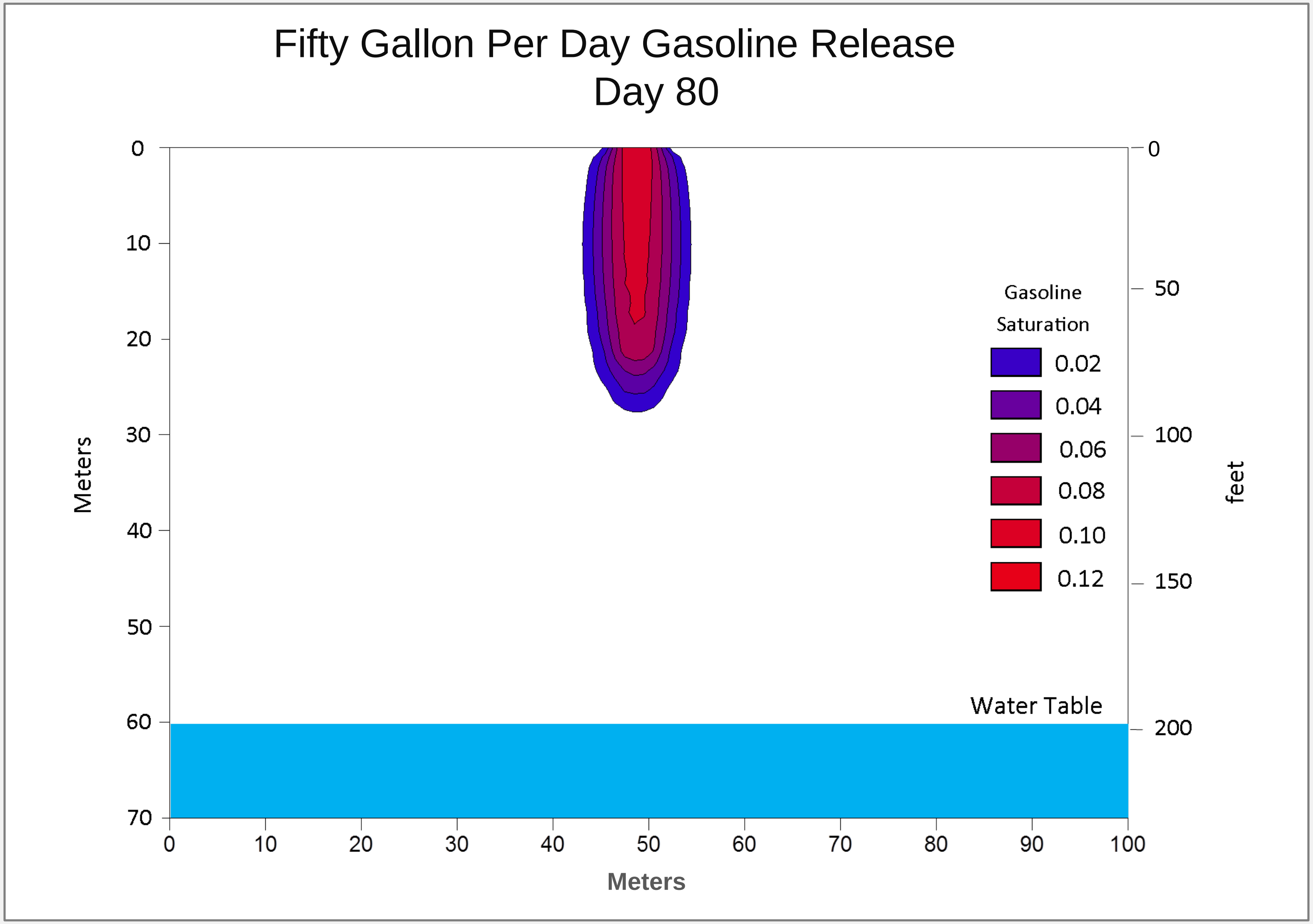

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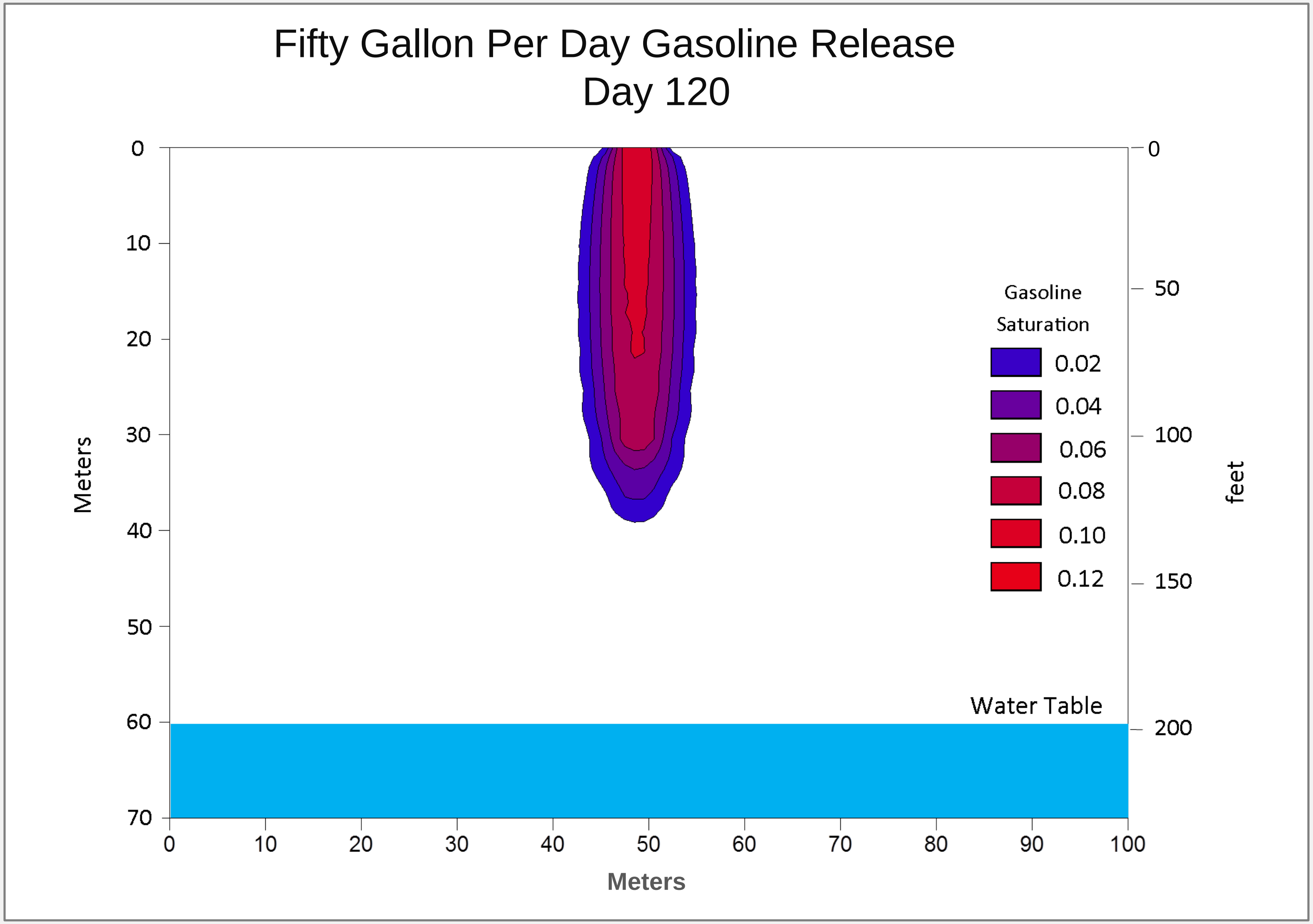

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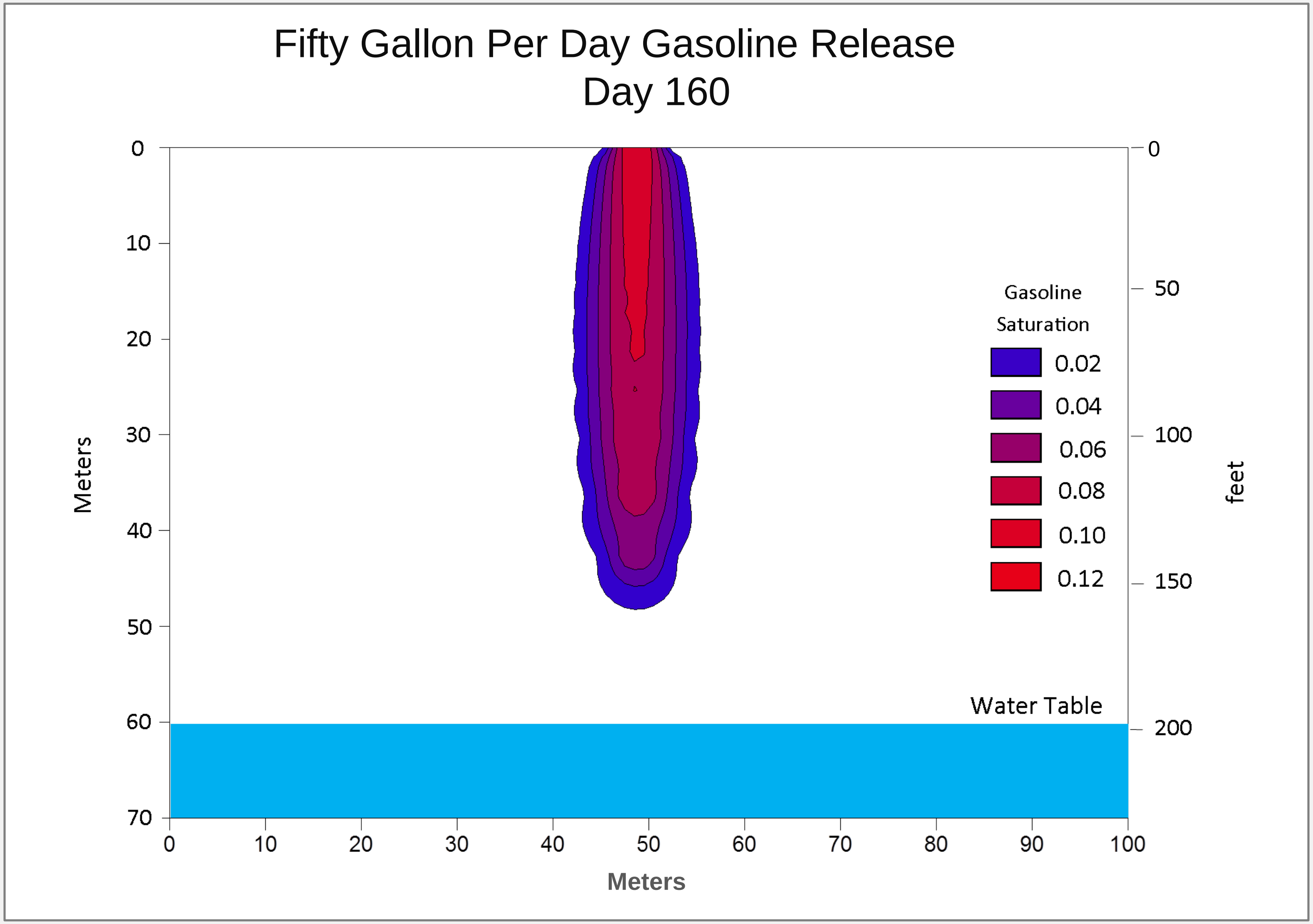

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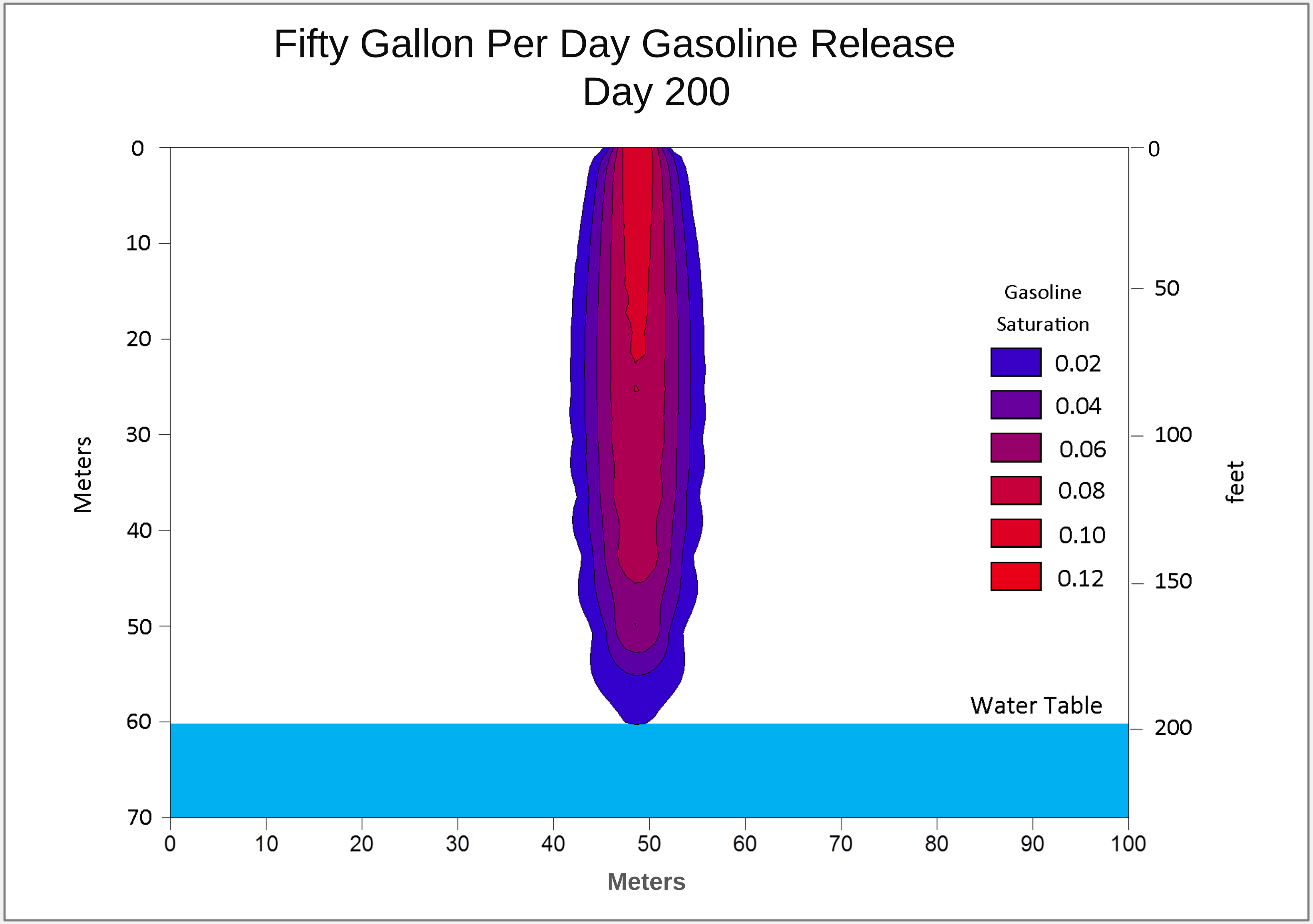

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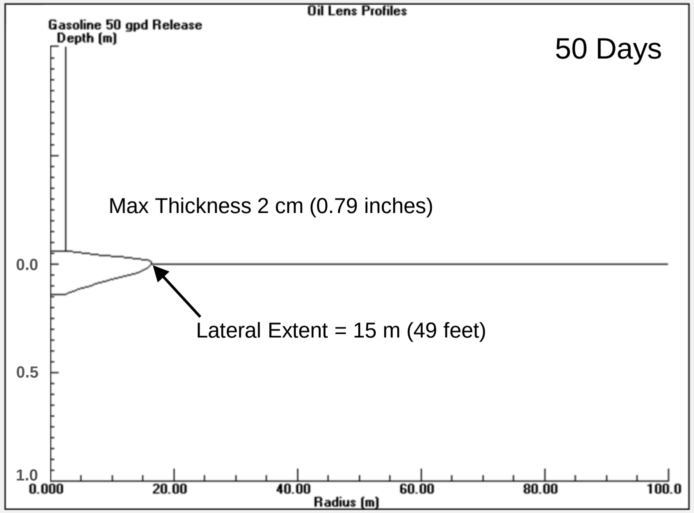
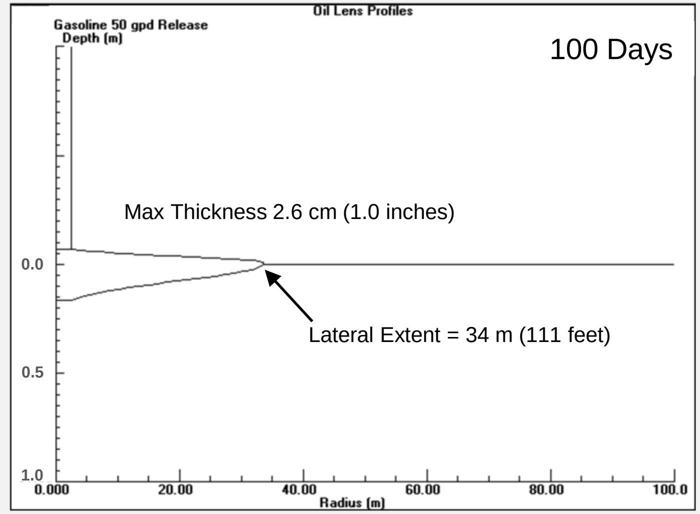
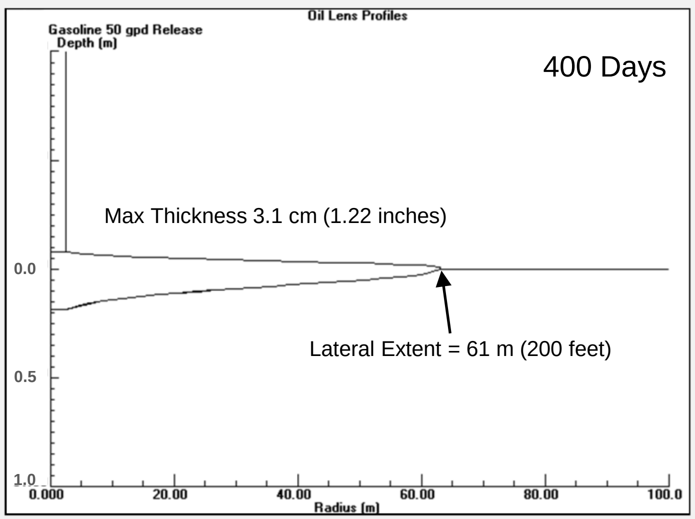
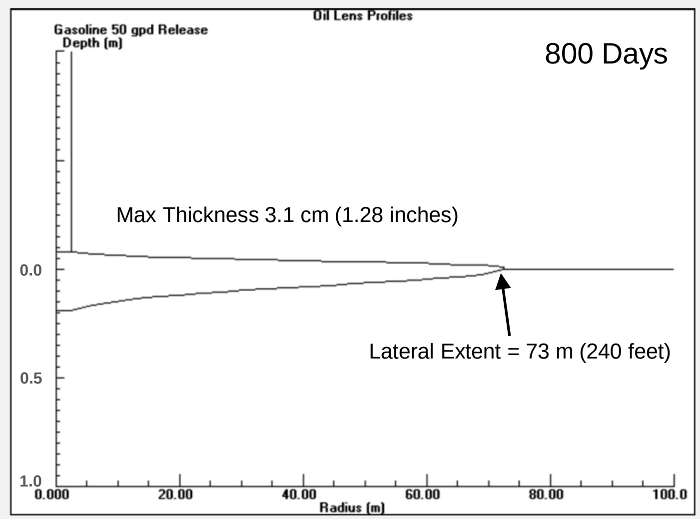
Continuous 50 gpd over 2.5 meter dia. circle









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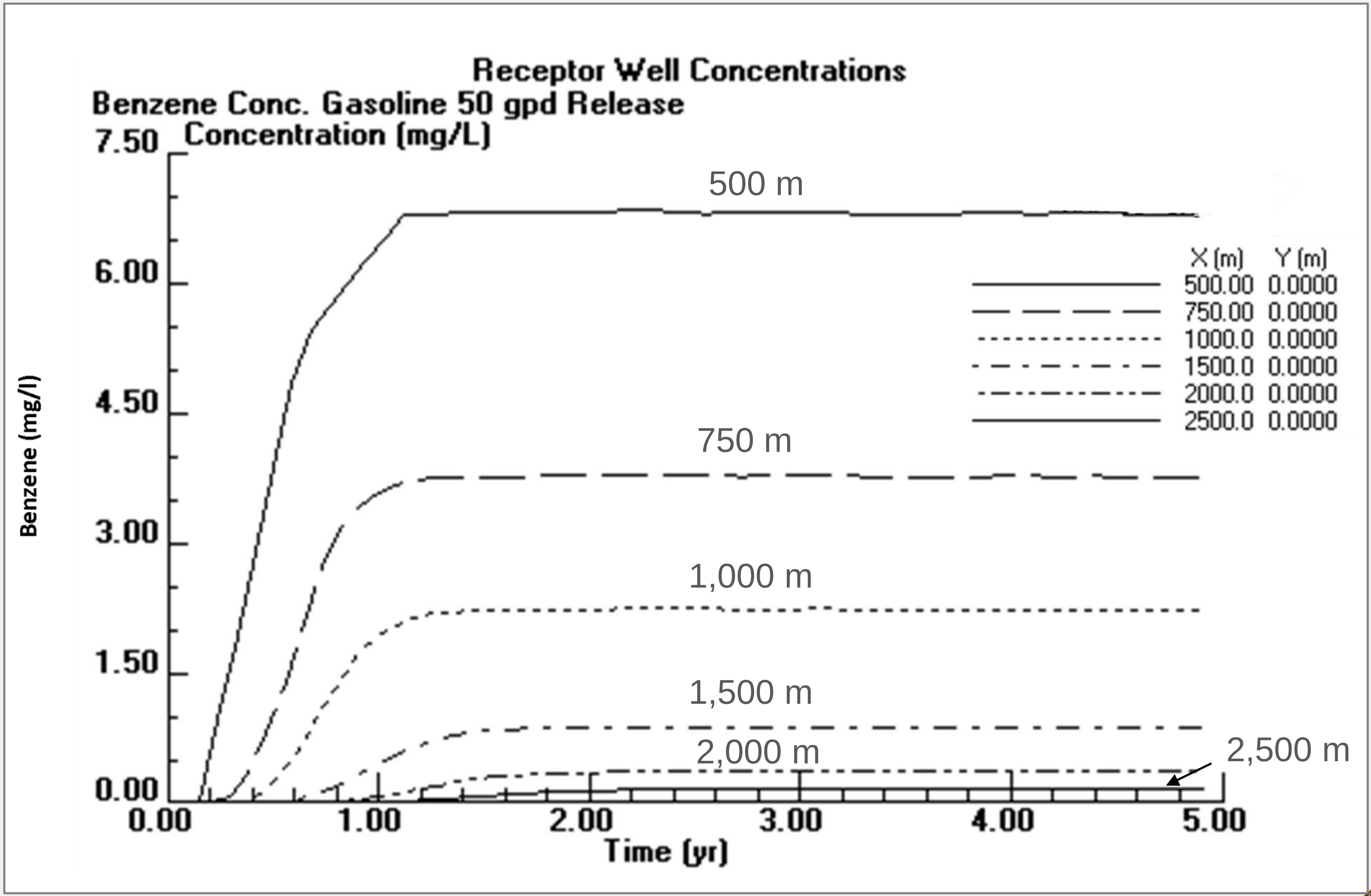
Drinking Water Standard = 0.005 mg/l



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Conclusions

1. EIA data indicates that rail delivered crude oil to PADD 5 does not appear to be currently decreasing and due to the lack of pipeline infrastructure will remain significant transport mode

2. Crude oil by rail and the Yellowstone pipeline are significant transporters of petroleum products over the RPA.

2. Large instantaneous releases of petroleum are very visible and will infiltrate into the subsurface but the depth will be limited by volume

4. Small continuous releases may be more difficult to detect and have the potential to infiltrate through the unsaturated zone and contaminate both the soil and ground water.

Questions

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